FINAL
GROUND PENETRATING RADAR AND SPONTANEOUS POTENTIAL SURVEYS

TECHNICAL MEMORANDUM

GALENA SUBSITE
CHEROKEE COUNTY SITE

FEBRUARY 1988
W.A. NO. 102-7L37.0

DE/CC11/035.1

DISCLAIMER

This report was prepared as an account of work sponsored by the U.S. Environmental Protection Agency (EPA). Neither the United States nor the U.S. EPA, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately-owned rights beyond the results presented herein. The report has not been prepared in sufficient detail to be the base of construction or remedial activity, and it is not sufficiently detailed to provide for the safety of people on site. Additional engineering work must be performed to fulfill these functions.

CONTENTS

TABLES

FIGURES

INTRODUCTION AND PURPOSE

The U.S. Environmental Protection Agency (EPA) used two different surface geophysical techniques, ground penetrating radar (GPR), and spontaneous potential (SP), at the Galena Subsite, Cherokee County Site, Kansas, during July and August 1987. The objectives of these techniques as outlined in the Work Plan, Supplementary Remedial Investigations for the Galena Subsite Mine Wastes Characterization and Geophysics (EPA, 1987), were to provide additional information, but not completely define, the following:

- The approximate extent of mine voids within the range of the GPR instrument
- The approximate volume of these mine voids
- The approximate water table elevation
- Generalized areas of active oxidation in mined and adjacent unmined locations

This additional information was required to complete the Groundwater/Surface Water Operable Unit Feasibility Study (OUFS) (EPA, 1988) for the Galena Subsite. This Technical Memorandum documents field activities involved in acquiring data, and presents and interprets that data. Specific topics include:

- Background of the study
- The use of GPR to help determine the extent and volume of mine voids and water table elevation

- The use of SP to determine areas of active oxidation
- A brief chronology of field task activities
- Results of GPR and SP field investigations
- Interpretations of GPR and SP field data

BACKGROUND OF STUDY

The Cherokee County Site lies within the extreme southeast corner of Kansas and represents the Kansas portion of the Tri-State Mining District (Figure 1). This area was formerly one of the largest lead and zinc ore deposits in the world. The site has been divided into six subsites based on the presence of physical surface effects of abandoned lead and zinc mining operations. The geophysical activities performed under this task were conducted on the Galena Subsite which is located in the east-central portion of the Cherokee County Site (Figure 1). Figure 2 shows the Galena Subsite boundaries and general location of the four geophysical survey areas.

Much of the current characterization data for the Galena Subsite were reported in the Final Draft, Phase I Remedial Investigation Report, Cherokee County, Galena Subsite (EPA, 1986) and the Groundwater/Surface Water OUFS (EPA, 1988). Overall, data from the geophysical surveys were obtained to fulfill the general objective of providing a more accurate assessment of subsite conditions for development of remedial alternatives for the Groundwater/Surface Water OUFS.

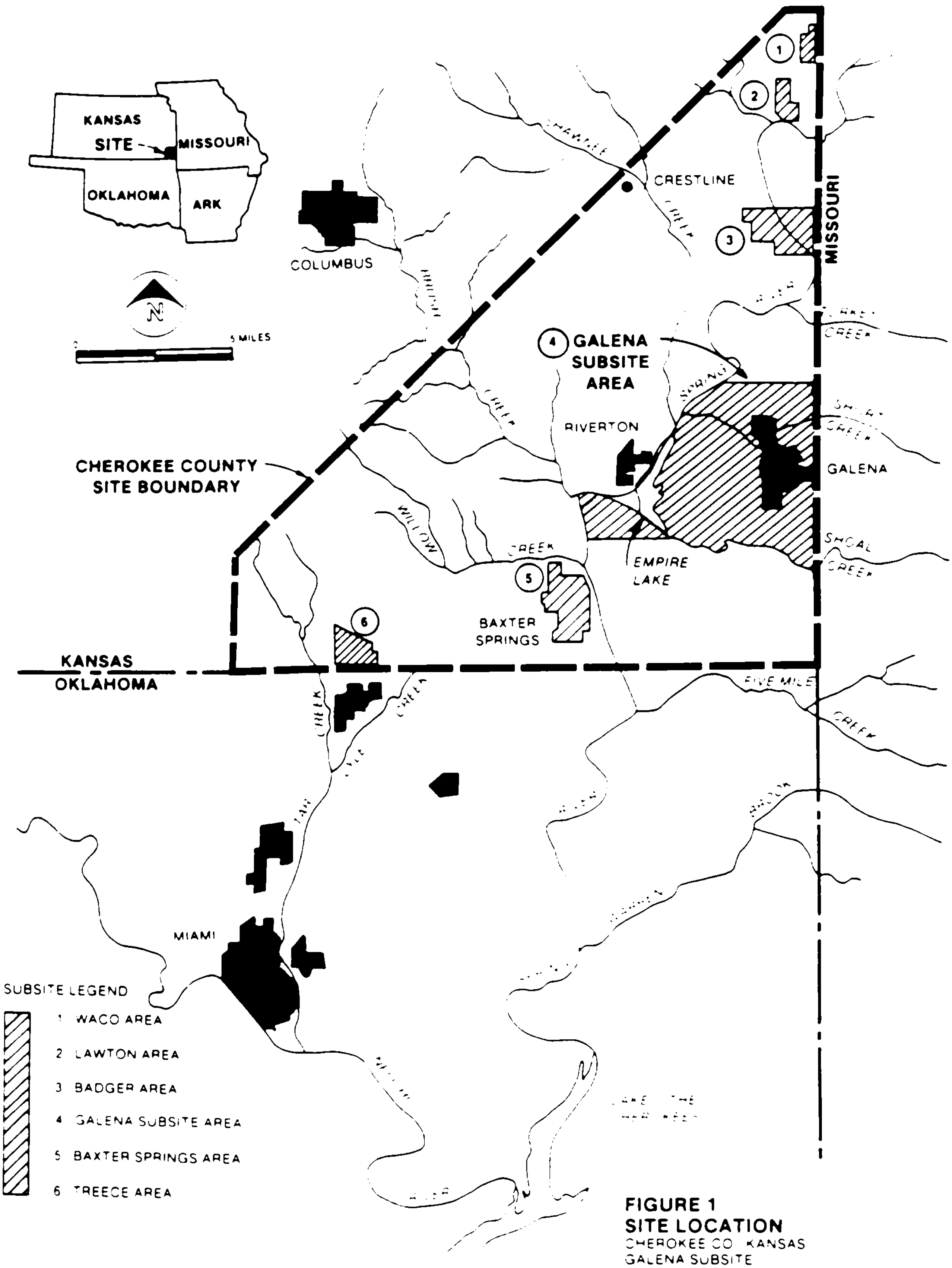
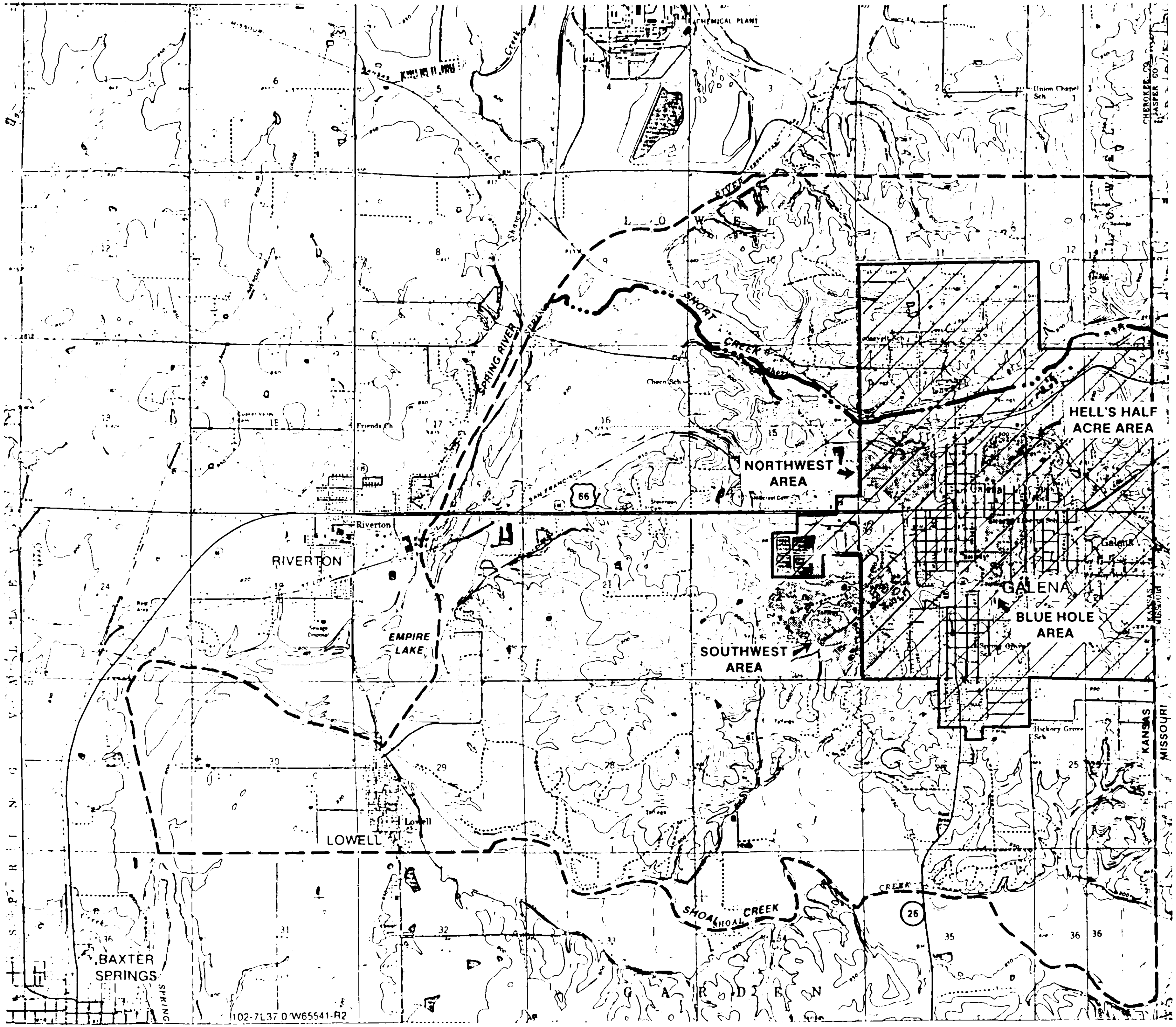


FIGURE 1
SITE LOCATION
CHEROKEE CO. KANSAS
GALENA SUBSITE



LEGEND

BOUNDARY OF GALENA SUBSITE

APPROXIMATE GALENA CITY LIMITS

GENERAL STUDY AREAS — GROUND PENETRATING RADAR SURVEY

N

0 1 2
SCALE IN MILES

FIGURE 2
GALENA SUBSITE
CHEROKEE CO., KANSAS
GALENA SUBSITE

METHODOLOGY

Two surface geophysical techniques were used at the Galena Subsite, GPR and SP. Data were collected by an experienced subcontractor under the supervision of CH2M HILL field personnel. The following sections describe the methodology used for collecting field data.

GROUND PENETRATING RADAR (GPR)

GPR data are collected by measuring the amplitude of electromagnetic energy reflected off boundaries between subsurface features. The amplitude of the reflected signal is a function of the material properties across the boundaries (Shih et al., 1986) and is plotted as a function of two-way travel time in nanoseconds (10^{-9} seconds). These data provide a profile of subsurface boundaries that, if the velocity characteristics of in-place materials are known, can be interpreted as being located at particular depths.

The GPR system configuration used at the Galena Subsite was a double 80-MHz antenna (transmitter and receiver). Data were acquired by towing the radar transmitter and receiver along surveyed lines. The reflected signals were amplified and displayed on a graphic profiler. This provided a continuous graphic display of the signals. A reference mark was placed on the continuous profile at 25-foot intervals. The continuous profile was monitored in the field and annotated with pertinent field observations as the data were being collected.

SPONTANEOUS POTENTIAL (SP)

SP data are collected by measuring a voltage difference between two ground locations using porous-pot electrodes

connected to a highly sensitive voltmeter. Two porous-pot electrodes (filled with a copper-sulfate solution) and a Fluke digital high-impedance voltmeter were used in collecting all SP data at the Galena Subsite.

A "leap frog" survey method was used. In this method, the trailing electrode was advanced beyond the forward electrode along the survey line. Dipole spacings were set at 50-foot intervals and the connecting wire was used to measure between stations. In areas of anomalous readings, spacings were shortened to 25-foot intervals to provide additional readings. Because initial testing of the method showed that wet pots provided more overall stability in reported SP readings over time (compared to dry pots), the ground was wetted with approximately 1 cup of water before placing each pot. Reproducibility of measurements and side-by-side voltage difference readings were checked periodically. All data were recorded in a field notebook. CH2M HILL field personnel monitored the results and plotted them in profile form at the end of each day.

BRIEF CHRONOLOGY OF FIELD TASK ACTIVITIES

7/28/87	The Earth Technology Corp. (TETC) field crew mobilized to the Galena Subsite.
7/29/87	After mobilization was completed, a health and safety briefing was held for the TETC field crew at the CH2M HILL field office. A site overview was performed in the afternoon.
7/30/87	The field crew checked out the GPR equipment. The recorder was not functioning properly, so the crew decided to run a SP test in the interim. They acquired SP test lines 1 and 2.
7/31/87	GPR equipment was functioning properly. The crew ran GPR test line A in Hell's Half Acre and continued with SP testing. They acquired SP test lines 3 and 4. Based on the SP test results, the

senior project geohydrologist decided to conclude SP testing and not conduct the remainder of the planned SP survey.

8/01/87 The crew acquired GPR test lines B and C. They reconnoitered the area southwest of town and set up two test lines for the next day.

8/02/87 The crew acquired GPR test lines D and E. Based on test results, they decided to conclude GPR testing and to conduct the GPR survey. They mobilized an additional TETC crew member from Golden, Colorado, to speed up acquisition of data on the GPR survey.

8/03/87 The crew acquired GPR survey lines 1, 2, and 3.

8/05/87 The crew acquired GPR survey lines 4, 5, 6, and 7. The GPR transmitter malfunctioned at end of day. The crew worked on repair.

8/06/87 The GPR equipment was still malfunctioning. The crew arranged for a replacement unit from a rental agency. They finished the day by surveying lines to be traversed when the replacement transmitter arrived.

8/07/87 The GPR rental equipment was in transit. The crew continued surveying lines for the GPR survey.

8/08/87 The GPR rental equipment was still in transit. The crew continued surveying lines.

8/09/87 The crew received a rental GPR antenna. They repeated GPR survey line 7 for comparison to previously acquired data. The comparison yielded similar results. The crew continued with the GPR survey. They acquired GPR survey lines 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, and 18 at the Blue Hole area. They moved to the area northwest of City Hall. They acquired GPR survey lines 19, 20, 21, and 22.

8/10/87 The crew acquired GPR survey lines 23, 24, 25, 26, and 27. They moved to the area southwest of town and acquired GPR survey lines 28, 29, 30, 31, 32, 33, 34, 35, and 36. They acquired GPR survey lines 37 and 38 in the Blue Hole and northwest areas, respectively. They moved back to the area southwest of town and acquired GPR survey lines 39 and 40.

8/11/87 The crew field checked all lines by walking transects and noting the surface location of potential interferences (metal debris, mine waste/rock boundaries, roads, power lines, heavy vegetation, etc.).

8/12/87 The crew demobilized from the Galena Subsite.

RESULTS

GROUND PENETRATING RADAR RESULTS

To achieve the previously stated objectives, a series of steps beginning with field testing and culminating in data interpretation were followed. These steps are covered in detail in the following sections.

GPR response, as previously mentioned, is related to a difference of physical properties found at layer boundaries. In the case of void space identification, the layer boundary is between rock and air (or rock and water in the case of water filled voids). Water table delineation depends on the layer boundary differences between saturated and unsaturated soil or rock.

The site-specific applicability of this geophysical method was determined using a series of GPR test lines over known mine voids, collapse features, and tied into mine shafts with known depths to water. Figure 3 illustrates where test lines were located. Five test lines with a total length of 1,170 linear feet were surveyed. The GPR responses along these test lines are provided in Appendix A.

Several features were displayed on the graphic GPR output that were not related to field phenomena. Figure 4 illustrates these features. The first feature, solid horizontal lines, are time markers placed on all survey lines from zero

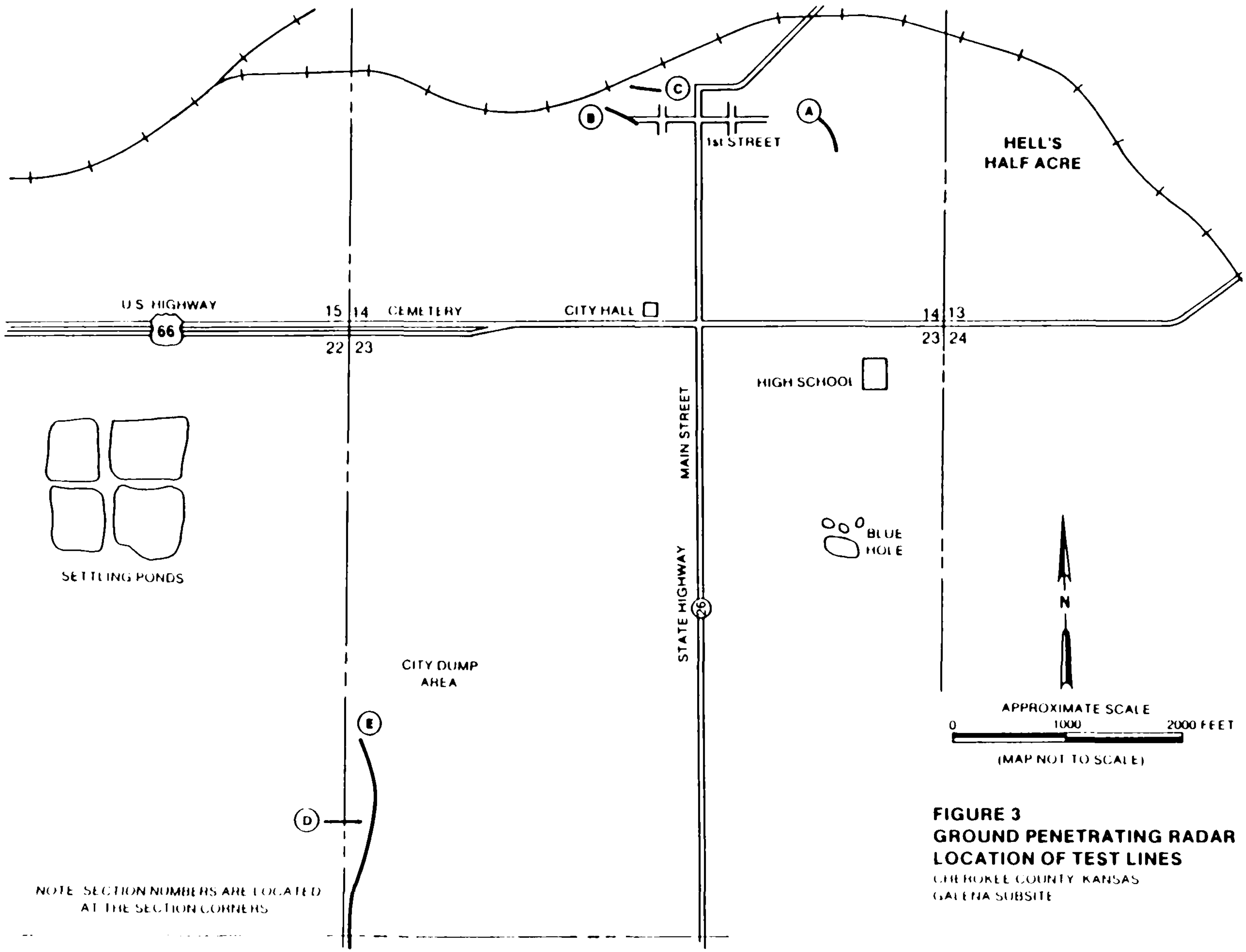


FIGURE 3
GROUND PENETRATING RADAR
LOCATION OF TEST LINES
CHEROKEE COUNTY, KANSAS
GALENA SUBSITE

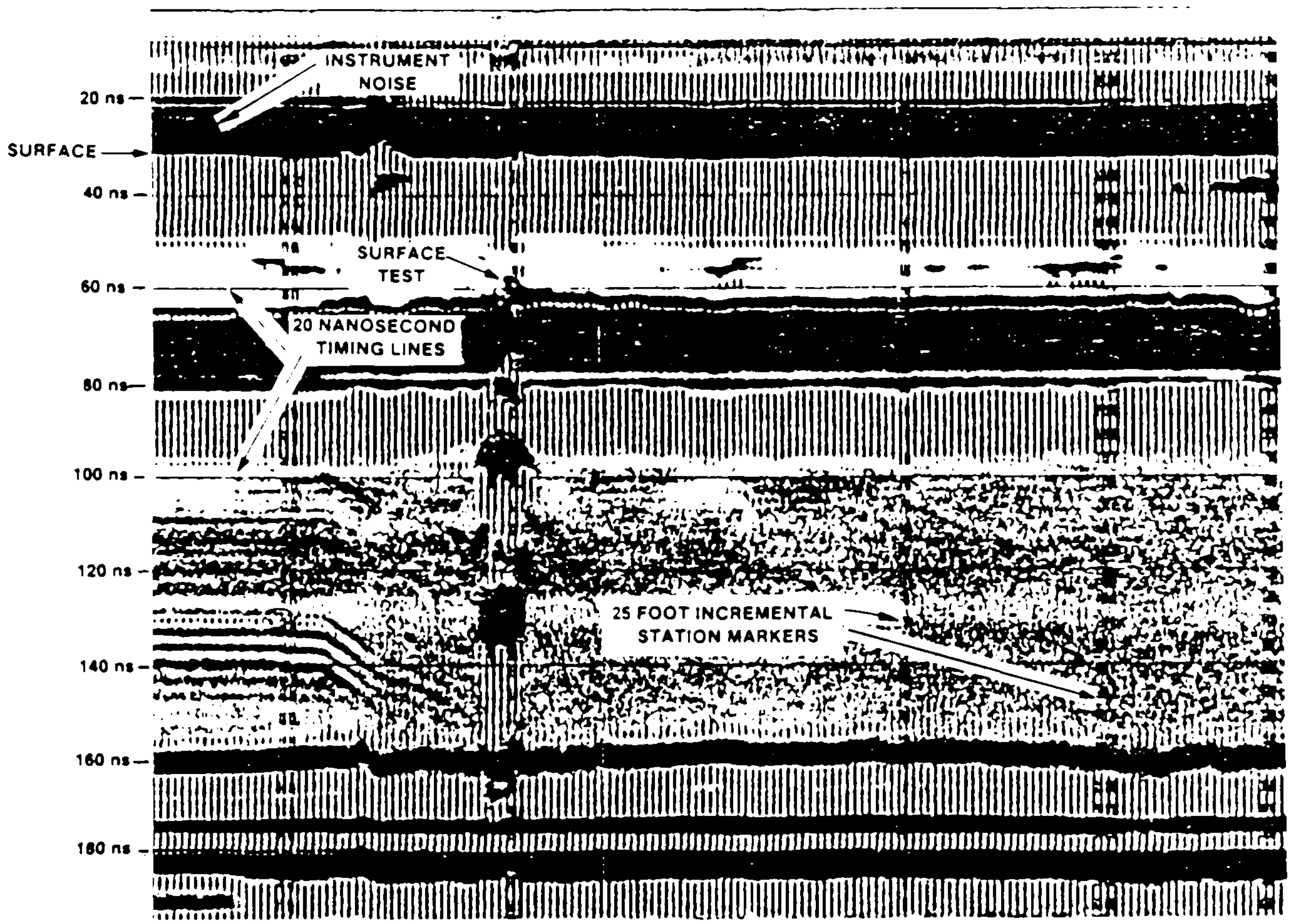


FIGURE 4
FEATURES ON GPR GRAPHIC PROFILE THAT ARE NOT RELATED TO FIELD PHENOMENON
CHEROKEE COUNTY KANSAS
GALENA SUBSITE

to 200 nanoseconds at 20-nanosecond increments (1 nanosecond = 10^{-9} seconds). The second feature, dashed vertical lines, are station markers placed on all survey lines at 25-foot increments. The third feature is a series of thick, dark horizontal bands, usually located at 25, 90, 169, and 180 nanoseconds. These bands are a function of the antenna/recorder configuration and represent instrument noise rather than ground response.

The last feature is a narrow parabolic reflector that occurs at the beginning of each line (labeled "surface test" in Figure 4). This feature is caused by a long strand of wire at the surface that is used to define the ground surface reflector. The first reflector that showed a response to this wire was taken to be the ground surface on the GPR profile.

Figure 5 illustrates the reflection profile obtained along GPR test line A. A mine void was found along this line. The cavity was connected to collapsed mine workings in the Hell's Half Acre area and was located between ground stations 30 and 80. The distance between the ground surface and the roof of the cavity measured 15 feet.

An interpretation of the GPR response (Figure 5) for the area where the void space occurred yields the following results:

- o The roof of the void space is seen as a continuous dark reflector.

- o Beneath the void space roof reflection is a series of multiple reflections (known as "ringing"). The multiple reflection pattern is caused by the extreme difference in layer properties between rock and

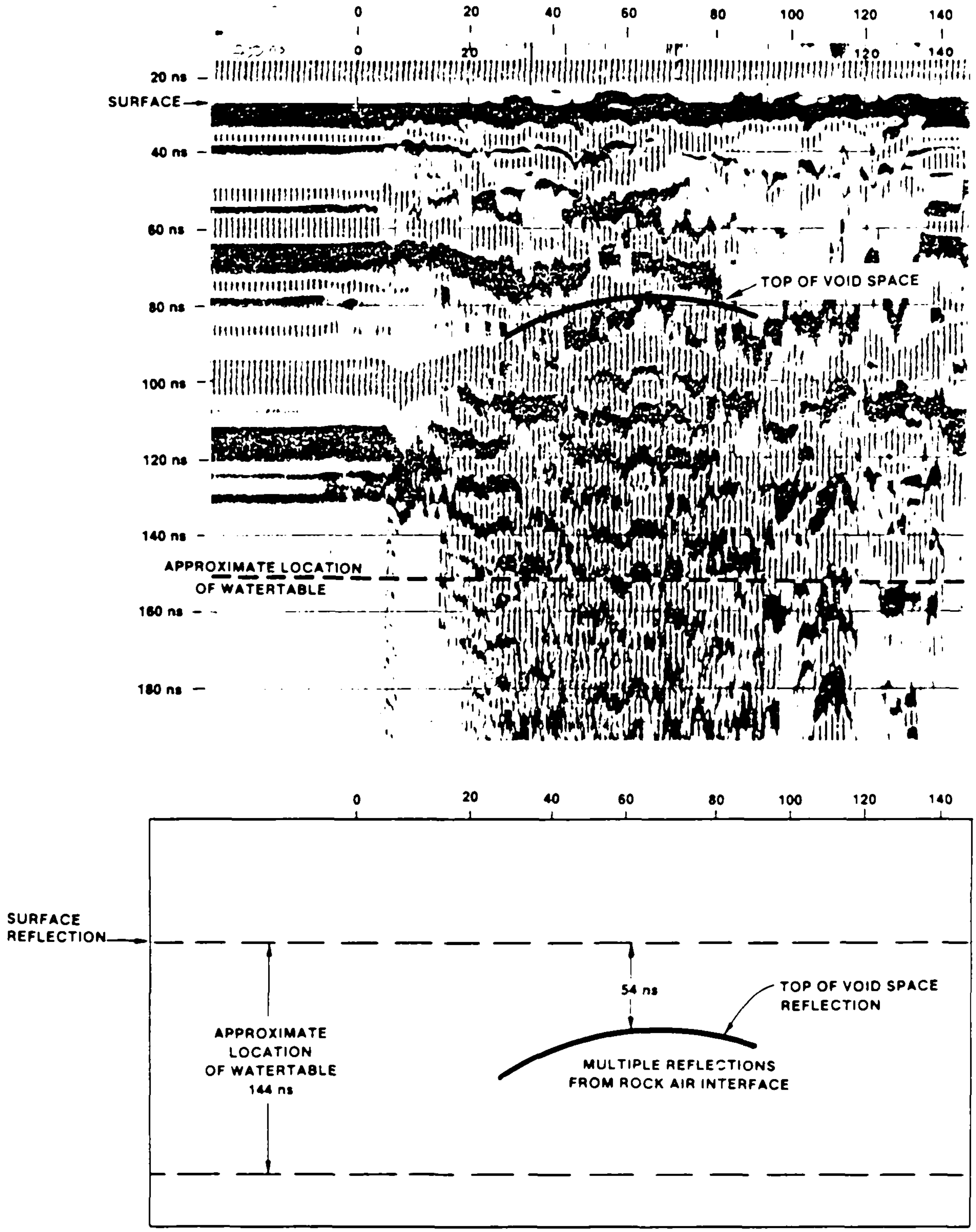


FIGURE 5
GPR TEST LINE A
REFLECTION PROFILE
CHEROKEE COUNTY KANSAS
GALENA SUBSITE

air. This extreme difference allows very little energy to penetrate past the rock/air interface. Events such as the floor of the void space are obscured by the combination of low energy returns and ringing multiples. Even if other features do exist within the depth GPR can see, they will not be detected if they occur beneath a void.

- The sides of the void are not seen as distinct walls. Instead, the roof reflections and associated multiples gradually taper off, approximately 10 feet past the actual field checked cavity sidewall. Reflections on a profile are derived from composite returns that have been averaged across an interface within an area of radiation. GPR effectively "sees" events ahead, behind, and to the side of an actual ground location.

  The distance away from the ground location that GPR sees is controlled by the geometry of the layer interface or, in this case, the geometry of the void walls. It is assumed that void wall geometry is relatively constant and that void space seen on a GPR profiler is approximately 20 feet greater than actual void space. This should be taken into account on any interpretation of subsurface void space.

The water table in the test area was 40 feet from the surface, as measured in nearby mine shafts. To determine whether or not there was an interpretable GPR response from the water table, it was necessary to convert the water table depth into two-way travel time in nanoseconds. This conversion would determine where the reflection on the GPR profile should be if GPR is seeing the water table. The depth from

ground level to the cavity roof on line A (Figure 5) was used to make this conversion, using the formula

$$\frac{t_a}{d_a} = \frac{t_b}{d_b}$$

where:

t_a = two-way time differential between surface, as measured on the profile reflector, and void roof reflector (54 nanoseconds)

d_a = depth to roof of void (15 feet, determined by field observation)

d_b = depth to water table (40 feet, determined by field observation)

t_b = two-way time differential between surface reflector and water table surface reflector

For test line A:

$$t_b = \frac{t_a \, d_b}{d_a} = \frac{54 \times 40}{15} = 144 \text{ nanoseconds}$$

A reflection from the water table should have occurred at 144 nanoseconds beneath the surface reflector if GPR was detecting the water table. No reflection occurred at that time interval, indicating that no water table was delineated.

Interpretation of GPR test lines B through E yielded results similar to the interpretation of line A. Test lines were selected to evaluate GPR under a variety of conditions. Measured depth to void spaces ranged from 15 to 40 feet, lines were located in three different areas, and lines were obtained in vegetated and nonvegetated cover. In each case,

voids observed in the field were located on a test line over a void area. No water table was observed on any of the test lines.

Given the success in locating subsurface voids, a total of 40 GPR survey lines, with a total length of 46,525 feet, were surveyed. Locations of these lines are shown in Figure 6.

GPR survey lines within the Galena Subsite were conducted at the following four general localities (Figure 6):

1. Hell's Half Acre--GPR survey lines 1 through 7

2. Blue Hole area--GPR survey lines 8 through 18 and 37

3. Southwest area--GPR survey lines 19 through 26 and 38

4. Northwest area--GPR survey lines 28 through 36 and 39 through 40

Appendix B contains annotated profiles along each line. Each GPR profile (graphic record) was examined as it was collected in the field. This enabled the field crew to examine the surface location of each recorded anomaly for any visible explanation as to the source of the GPR response. An ongoing catalogue of GPR responses to surface and subsurface phenomena was developed and used for preliminary interpretation of each line as it was acquired.

The GPR profiles along these lines were interpreted by collecting GPR data over known features then correlating unknown responses with known responses. There were four common GPR patterns.

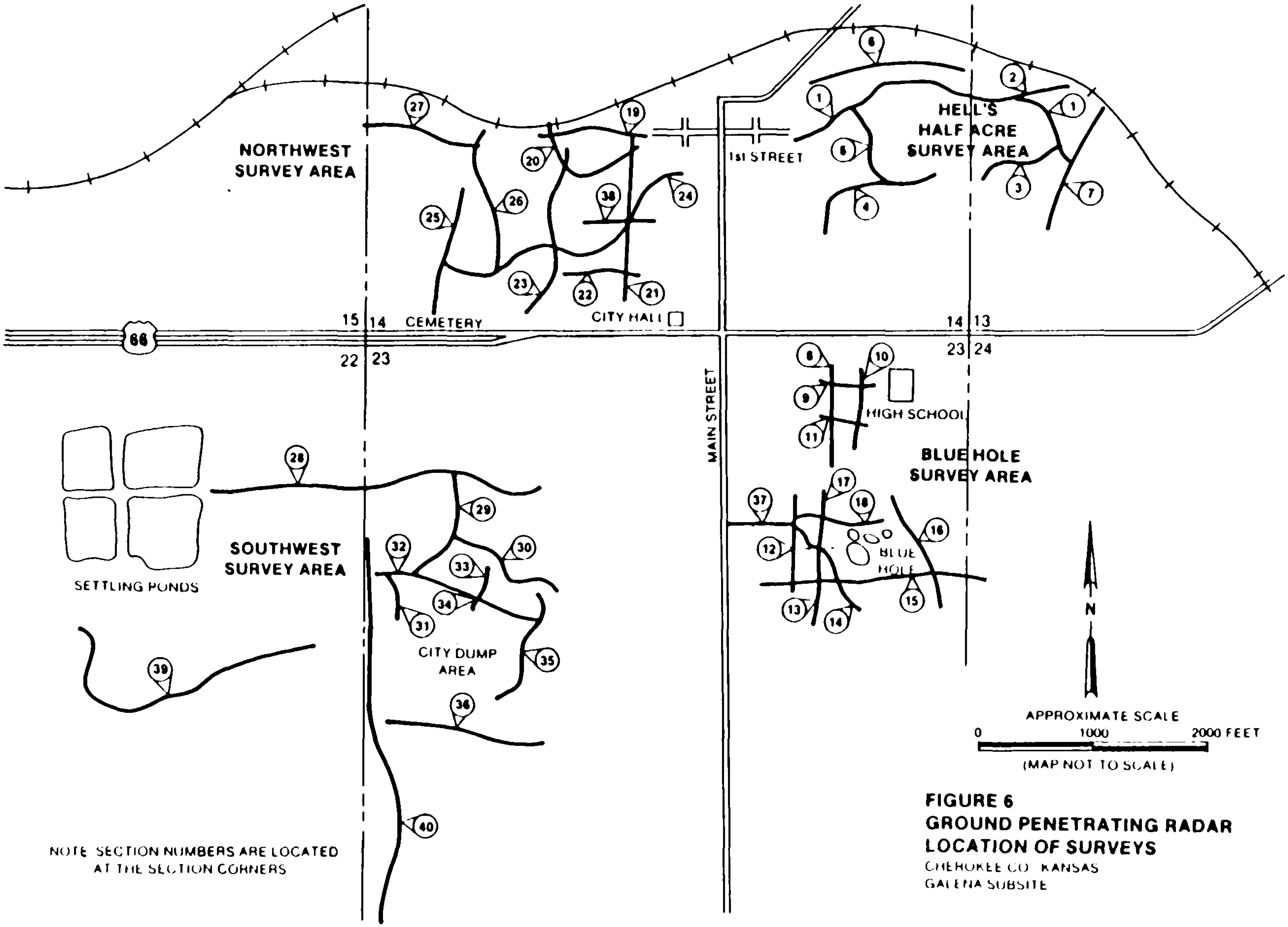


FIGURE 6
GROUND PENETRATING RADAR
LOCATION OF SURVEYS
CHEROKEE CO. KANSAS
GALENA SUBSITE

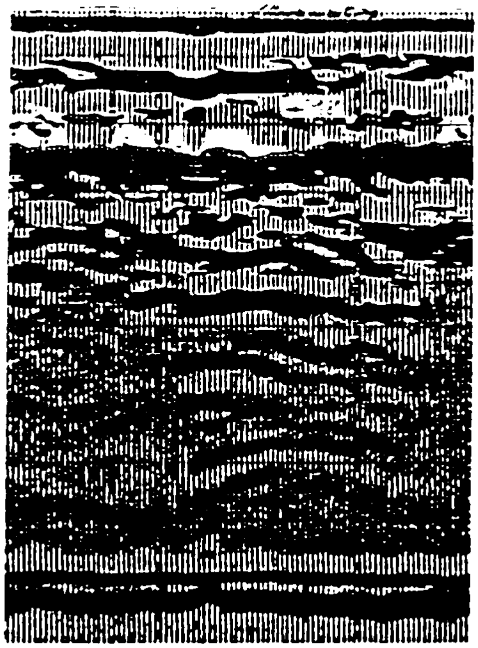
Void Space. Void space consists of abandoned mine workings (including buried shafts and horizontal tunnels), potential subsidence areas related to mine workings, and other cavities unrelated to mining. Figure 7 presents examples of the pattern response of suspected subsurface voids.

Disturbed Areas. Disturbed areas typically consist of mine shafts and surface or subsurface mine features, frequently used to dispose of or store mining byproducts. Mine wastes, chat piles, boulders from shaft excavation, and backfilled areas are examples of disturbed areas. Figure 8 presents response patterns for known and suspected disturbed areas.

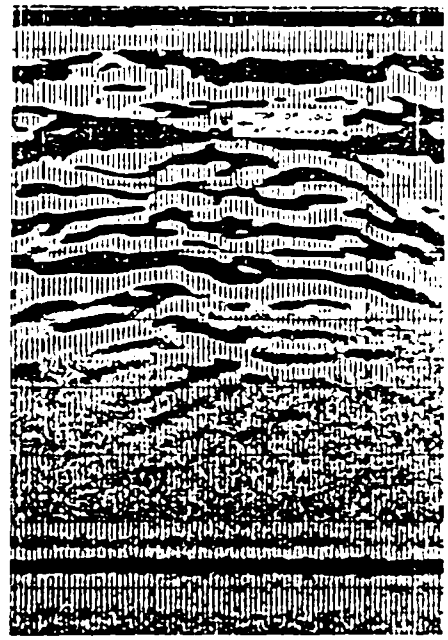
Other Physical Features. Other physical features are man-made objects not necessarily part of the mine workings including power lines, buried utilities, culverts, railroad tracks, fences, road beds, and municipal trash. Since GPR response is very sensitive to metal objects, cultural features composed of metal have very distinct patterns. Figure 9 presents response patterns for several of the above-mentioned physical features.

Undetermined Responses. Undetermined responses were anomalies that did not match reference patterns established during testing. Ground observations at the surface did not reveal causes for these responses. The cause could not be determined without conducting further ground truthing (borings, drill holes, or trenching), which was beyond the scope of this study. Figure 10 presents pattern responses for unrecognized responses.

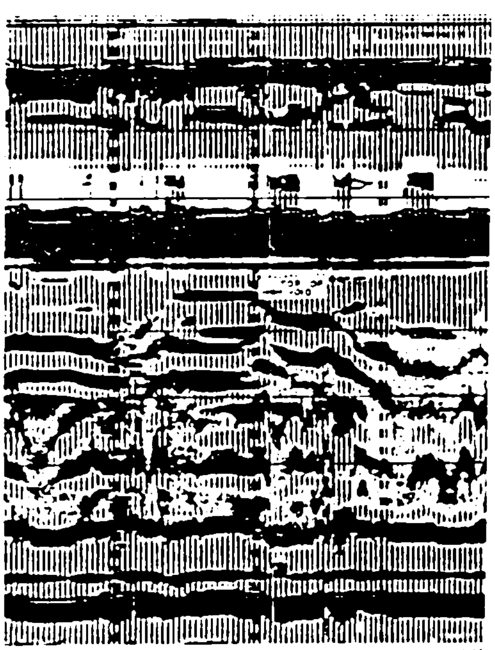
Each of the 40 GPR lines was interpreted for the presence of voids. When a void was suspected, its location along the line was noted and an estimate of depth to the top of the void was made. (Conversion of two-way travel time to void-top depth used the value of 1.8 nanoseconds per foot, which



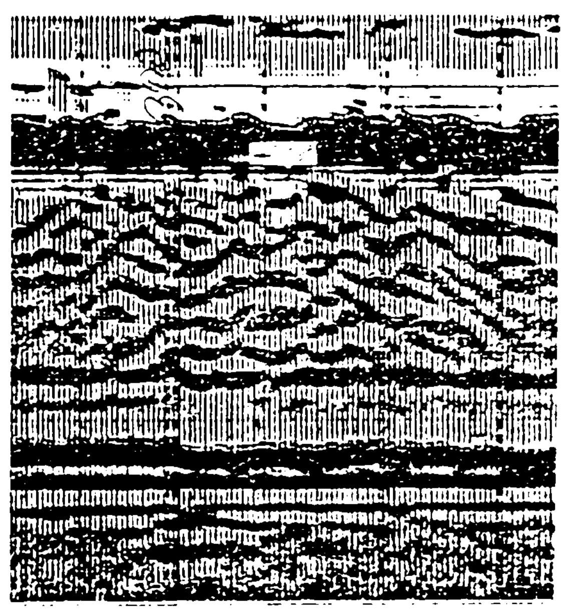
LINE 1 STA. 2600-2675
VOID



LINE 2 STA. 35-75
VOID

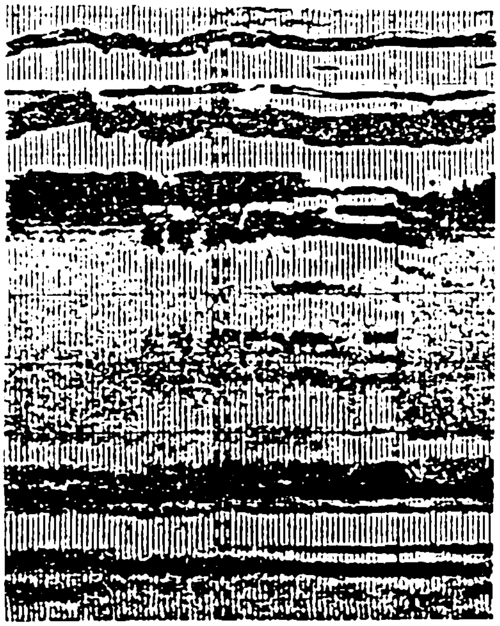


LINE 21 STA. 815-860
VOID

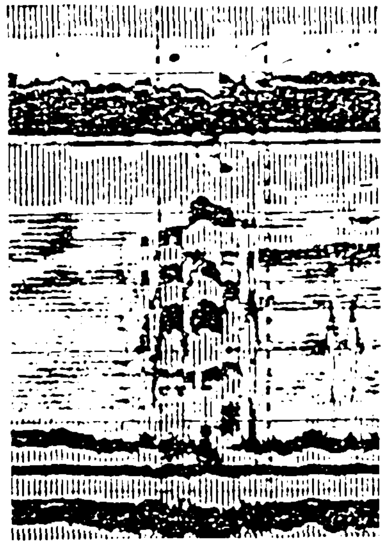


LINE 26 STA. 260-425
VOID

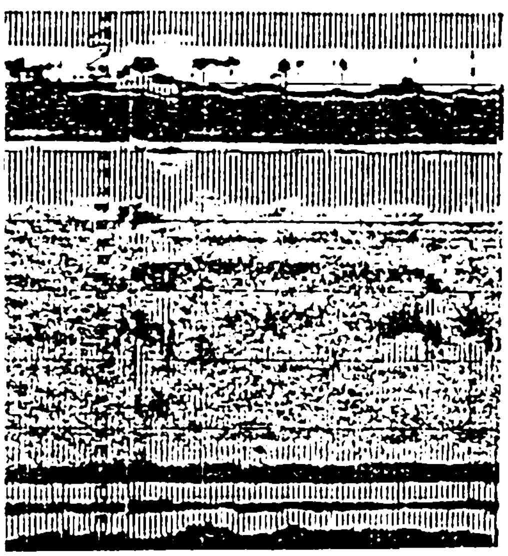
FIGURE 7
EXAMPLES OF VOID SPACE GPR RESPONSE PATTERNS
CHEROKEE COUNTY KANSAS
GALENA SUBSITE



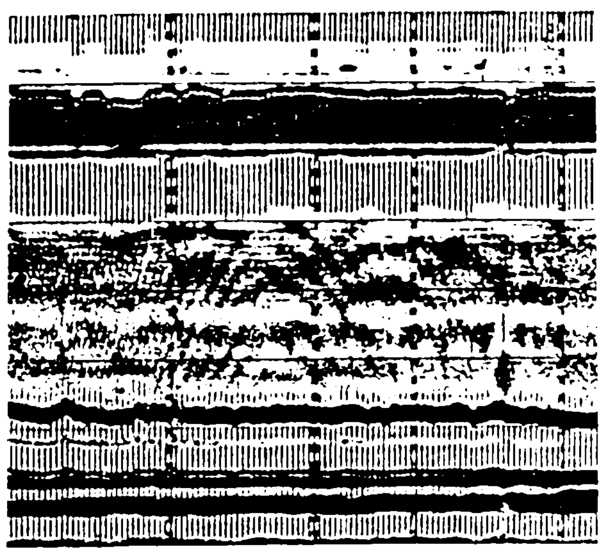
LINE 4 STA. 90-140
BROKEN UP GROUND
ROUGH TERRAIN



LINE 13 STA. 150-225
BOULDERS

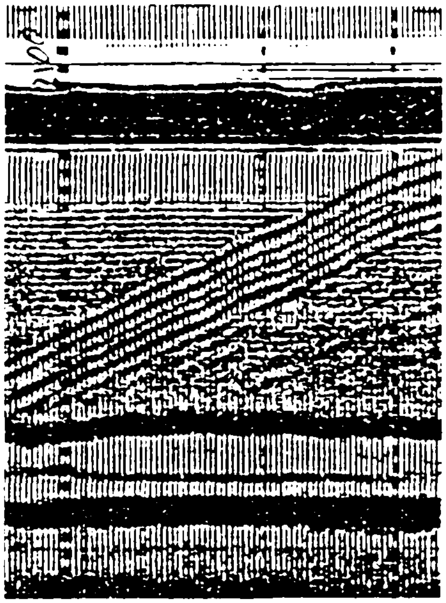


LINE 15 STA. 500-600
CHAT PILES

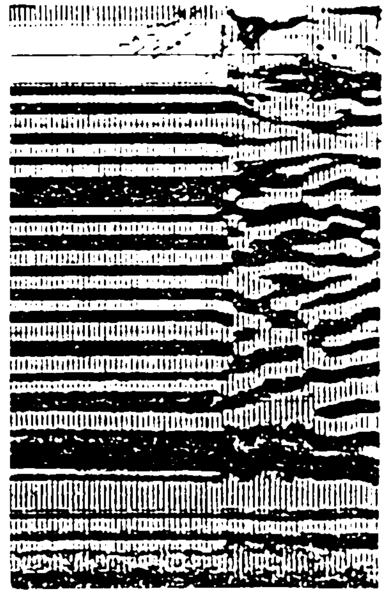


LINE 21 STA. 1025-1075
FRACTURE ZONES

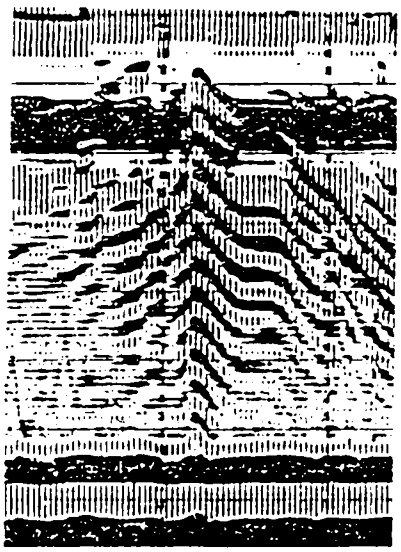
FIGURE 8
EXAMPLES OF DISTURBED AREA
GPR RESPONSE PATTERNS
CHEROKEE COUNTY KANSAS
GALENA SUBSITE



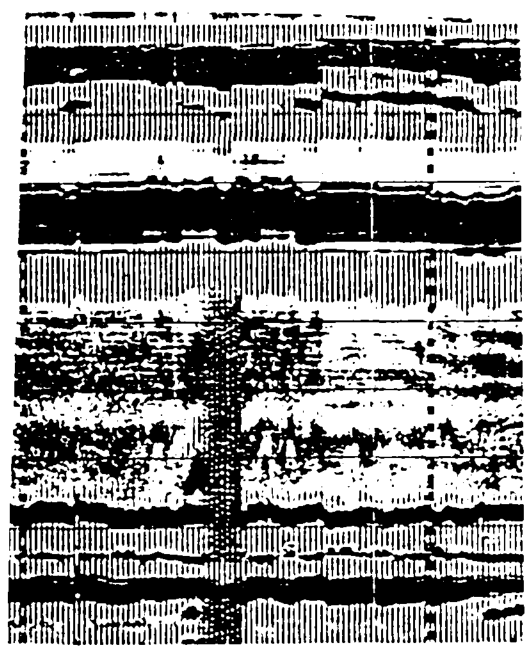
LINE 40 STA. 2075-2175
POWERLINE



LINE 6 STA. 0-25
IN PLACE GPR RESPONSE

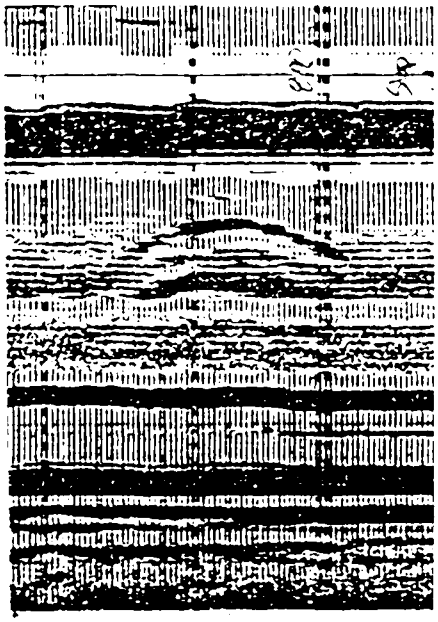


LINE 10 STA. 300-425
BURIED UTILITY

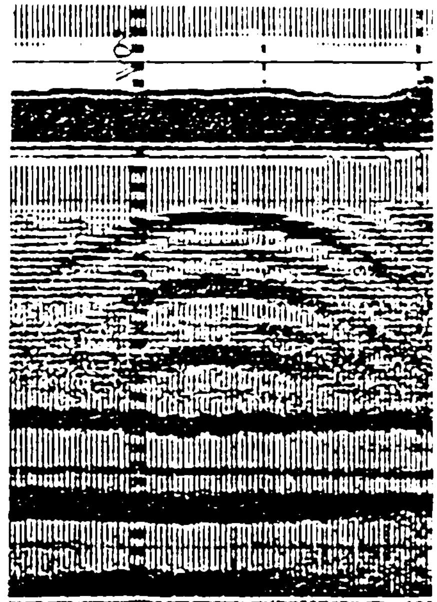


LINE 21 STA. 525-600
FM TRANSMISSION

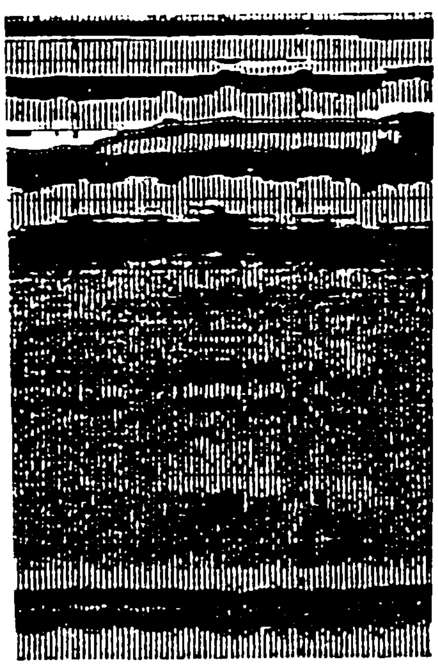
FIGURE 9
EXAMPLES OF OTHER PHYSICAL FEATURES
GPR RESPONSE PATTERNS
CHEROKEE COUNTY, KANSAS
GALENA SUBSITE



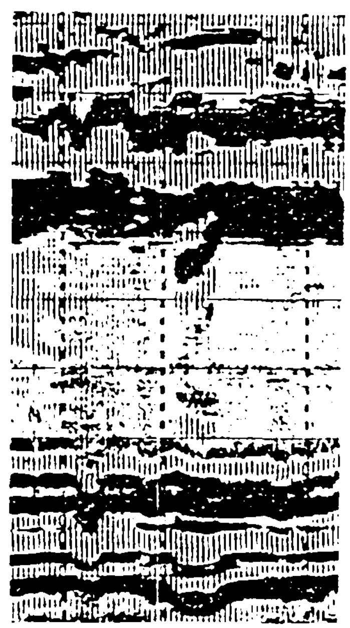
LINE 26 STA. 750-800
UNDETERMINED RESPONSE



LINE 40 STA. 1075-1150
UNDETERMINED RESPONSE



LINE 1 STA. 1650-1675
UNDETERMINED RESPONSE



LINE 5 STA. 525-625
UNDETERMINED RESPONSE

FIGURE 10
EXAMPLES OF UNDETERMINED GPR RESPONSE PATTERNS
CHEROKEE COUNTY KANSAS
GALENA SUBSITE

was experimentally determined during the test phase of GPR). Disturbed areas, other physical features, and unrecognized responses were also identified along each line. Field observations were used to cross-reference each of the anomalies to provide additional information on the source of the GPR response pattern.

Table 1 shows location and depth of subsurface voids and disturbed areas for each line based on interpretation of GPR data. Table 2 shows location and description of other physical features and undetermined responses for each line based on interpretation of GPR data and observation. Lines are listed in the order they were acquired in each locality.

Since field-truthing of the reported GPR anomalies by drilling was not practical, verifying accuracy of interpretation was accomplished by comparing GPR results with existing mine maps. Two maps were used in this comparison: a U.S. Department of Interior Bureau of Mines map (McCauley et al., 1983) and an unpublished Galena Mining District Map (Stewart, 1987). The Stewart map was not obtained until after the GPR field study was completed. Information from both these maps was combined to produce composite maps, which are shown in Figures 11 through 14. These maps differentiate collapse features, shallow mine workings (elevation of floor <40 feet below surface), and deep mine workings (elevation of floor <40 feet below surface) within each of the four general GPR survey areas.

The GPR lines were overlain onto this map and compared for location of void space. For clarity, the GPR-located voids are shown as a wider line on Figures 11 through 14. This is not meant to imply that lateral measurements were made since GPR was used only to locate voids along a line.

Table 1
SUMMARY OF GROUND PENETRATING RADAR (GPR) DATA--GALENA SUBSITE
SUBSURFACE VOIDS AND DISTURBED AREAS

GPR Survey Area	GPR Line No.[a]	Line Direction of Travel[b]	Total Line Length (ft)	Subsurface Voids: Location On-Line[c] (ft)	Subsurface Voids: Depth to Top of Void[d] (ft)	Disturbed Areas: Location On-Line[c] (ft)	Description
Hell's Half Acre	1	W to E	3,000	325-350 550 2,300-2,450 2,490-2,675 2,790	9 8 8 8 19	0-3,000	
	2	W to E	950	35-75 875	6-10 15	0-950 300 390-415 490-525 560-630	
	3	E to W	350	125-350	8.5	0-350	
	4	S to N (W to E)	1,750			-400 to 1,350[e]	
	5	S to N	700	115-135 135-200	16.5 Filled	25-75	
	6	W to E	1,075	0-1,075	6	300-400 725-825	
	7	N to S	1,000	110-370	19		
Blue Hole	8	S to N	1,000	325-375	9		
	9	W to E	400			125	Trench
	10	N to S	625	---[f]			
	11	E to W	425	---[f]			
	12	N to S	1,000	---[f]			
	13	S to N	575			150-225	Boulders
	14	N to S	800			525-575	
	15	W to E	1,700	175-265	21	75-100	Gravel
	16	N to S	950			950 915	
	17	N to S	400	190	25	250-400	Rough surface
	18	W to E	975	-200	26	225 550-575	Stream bed
	37	E to W	325	---[f]			
Northwest	19		800	750-800	16		

[a]Refer to Figure 6 for line location.

[b]Direction of travel refers to the direction taken by the actual field crew for each line.

[c]Location of various responses along the line is measured from the beginning of the line of travel.

[d]Depths are based on geophysicist's interpretation and have not been field checked for accuracy.

[e]Line 4 begins at Station -400.

[f]A blank following after a line indicates that no interpretable phenomena were recorded on the GPR line.

Table 1
(continued)

GPR Survey Area	GPR Line No.[a]	Line Direction of Travel[b]	Total Line Length (ft)	Subsurface Voids Location On-Line[c] (ft)	Subsurface Voids Depth to Top of Void[d] (ft)	Disturbed Areas Location On-Line[c] (ft)	Description
Northwest (continued)	20	W to E	800	0-110	10 to top	380 535-800	Ditch Rough surface
	21	N to S	1,175	380-430 815-860	33 30	200-250 1,025-1,075	
	22	E to W	500			0-500	
	23	S to N	1,450			0-75	
	24	E to W	2,850	2,330-2,400 2,500-2,600	12 15	55-65 1,425-1,475 2,200	 Stream bed
	25	S to N	800	---[f]			
	26	S to N	1,275	0-425 450 515 550-725 1,000-1,075 1,200-1,230	20 20 30 20 25 28		
	27	E to W	2,700	175 225-325 400-500 600-625 875-925 990-1,115	28 28 28 28 		
	38	E to W	800	3		350-750	Chat
Southwest	28	W to E	2,450	---[f]			
	29	N to S	1,500	---[f]			
	30	E to W	900			350-375 410-550	
	31	S to N	325			0-25	
	32	W to E	775	---[f]			
	33	S to N	375	---[f]			
	34	W to E	450			1,325-1,350	
	35	N to S	1,000			350-475 700-825	
	36	E to W	1,500	650-675 725-825	26 23		
	39	W to E	3,300			700-800	
	40	S to N	3,100			1,125	

[a]Refer to Figure 6 for line location.

[b]Direction of travel refers to the direction taken by the actual field crew for each line.

[c]Location of various responses along the line is measured from the beginning of the line of travel.

[d]Depths are based on geophysicist's interpretation and have not been field checked for accuracy.

[e]Line 4 begins at Station -400.

[f]A blank following after a line indicates that no interpretable phenomena were recorded on the GPR line.

Table 2
SUMMARY OF GROUND PENETRATING RADAR (GPR) DATA--GALENA SUBSITE
OTHER PHYSICAL FEATURES AND UNDETERMINED RESPONSES

GPR Survey Area	GPR Line No.[a]	Line Direction of Travel[b]	Total Line Length (ft.)	Other Physical Features: Location On-Line[c] (ft.)	Other Physical Features: Description	Undetermined Response Location Online[c] (ft.)
Hell's Half Acre	1	W to E	3,000	525	Culvert	550
				750	Trash	600
				1,125	Trash	850-875
				1,175	Trash	1,650-1,675
				1,500	Trash	
				2,300-2,450		
				2,500		
	2	W to E	950	---[d]		
	3	E to W	350	---[d]		
	4	S to N (W to E)	1,450	-400 to 0	Powerline	
	5	S to N	700	---[d]		
	6	W to E	1,075	---[d]		
	7	N to S	1,000	0-75	RR Tracks	
				760-1,000	Powerline	
Blue Hole	8	S to N	1,000	0-125	Powerline	
				275-325	Fence	
				650	Utility	
	9	W to E	400	100	Utility	
				325-400	Fence Powerline	
	10	N to S	625	300-425	Utility	
				475-500	Pipe	
				610-625	Fence	
	11	E to W	425	50-80	Pipe	
				350-400	Powerline	
	12	N to S	1,000	0-350	Powerline	
				800-825	Road	
	13	S to N	575	0-100	Powerline	
	14	N to S	800	600-625	Concrete Slab	
				675-710	Berm	
	15	W to E	1,700	>1,700	Powerline	
	16	N to S	950	<50	Powerline	

[a]Refer to Figure 6 for line location.

[b]Direction of travel refers to the direction taken by the actual field survey for each line.

[c]Location of various responses along the line is measured from the beginning of the line of travel.

[d]A blank following after a line indicates that no interpretable phenomena were recorded on the GPR line.

Table 2
(continued)

				Other Physical Features		
GPR Survey Area	GPR Line No.[a]	Line Direction of Travel[b]	Total Line Length (ft.)	Location On-Line[c] (ft.)	Description	Undetermined Response Location Online[c] (ft.)
Blue Hole (continued)	17	N to S	400	10	Powerline	
	18	W to E	975	650	Berm	
	37	E to W	325	175-225 290-325		
Northwest	19	E to W	800	---[d]		
	20	W to E	800	175-200	Trash	
	21	N to S	1,175	430 560	Powerline FM Radio Transmission	
	22	E to W	500	---[d]		
	23	S to N	1,450	150 600-900 1,100 1,385		
	24	E to W	2,850	2,100-2,135		450 1,990
	25	S to N	800	0-175		
	26	S to N	1,275			750-800
	27	E to W	2,700	300 875		1,150
	38	E to W	800	---[d]		
Southwest	28	W to E	2,450	0-25 1,200-1,825 1,950-2,175 2,300-2,450	 Powerline Buildings Powerline	
	29	N to S	1,500			1,325-1,525
	30	E to W	900			
	31	S to N	325			525-625
	32	W to E	775			
	33	S to N	375			375-175

[a]Refer to Figure 6 for line location.

[b]Direction of travel refers to the direction taken by the actual field survey for each line.

[c]Location of various responses along the line is measured from the beginning of the line of travel.

[d]A blank following after a line indicates that no interpretable phenomena were recorded on the GPR line.

Table 2
(continued)

GPR Survey Area	GPR Line No.[a]	Line Direction of Travel[b]	Total Line Length (ft.)	Other Physical Features: Location On-Line[c] (ft.)	Other Physical Features: Description	Undetermined Response Location Online[c] (ft.)
Southwest (continued)	34	W to E	450	---[d]		
	35	N to S	1,000	---[d]		
	36	E to W	1,500			
				1,350-1,450		
				1,550	Powerline	
	39	W to E	3,300	1,200-1,250		
				3,225-3,300		
	40	S to N	3,100	2,075-2,450	Powerline	1,075-1,150
				3,000-3,100	Powerline	

[a]Refer to Figure 6 for line location.

[b]Direction of travel refers to the direction taken by the actual field survey for each line.

[c]Location of various responses along the line is measured from the beginning of the line of travel.

[d]A blank following after a line indicates that no interpretable phenomena were recorded on the GPR line.

FIGURE 11
HELL'S HALF ACRE GPR SURVEY — VOID RESPONSES
CHEROKEE COUNTY, KANSAS
GALENA SUBSITE

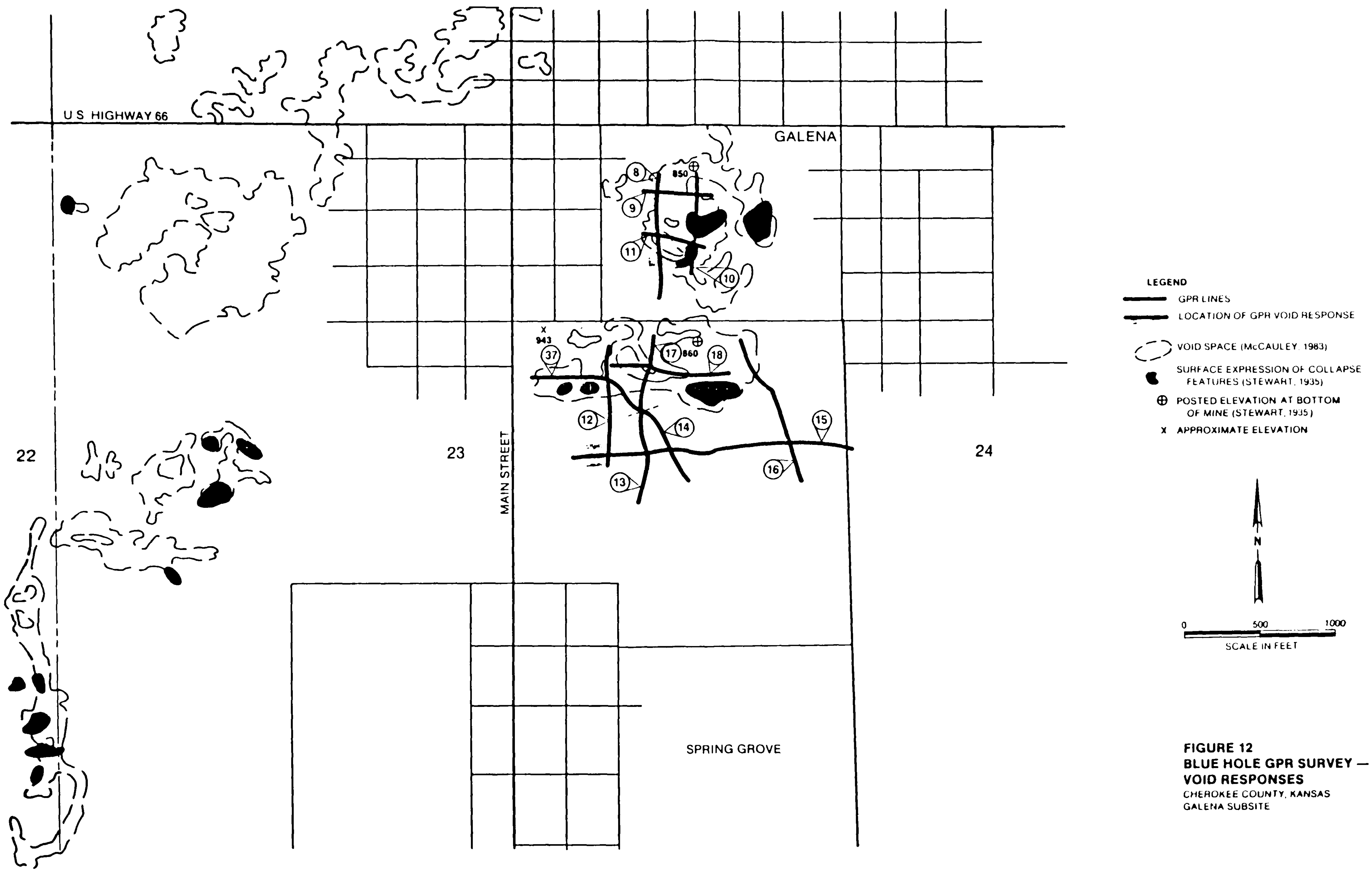


FIGURE 12
BLUE HOLE GPR SURVEY — VOID RESPONSES
CHEROKEE COUNTY, KANSAS
GALENA SUBSITE

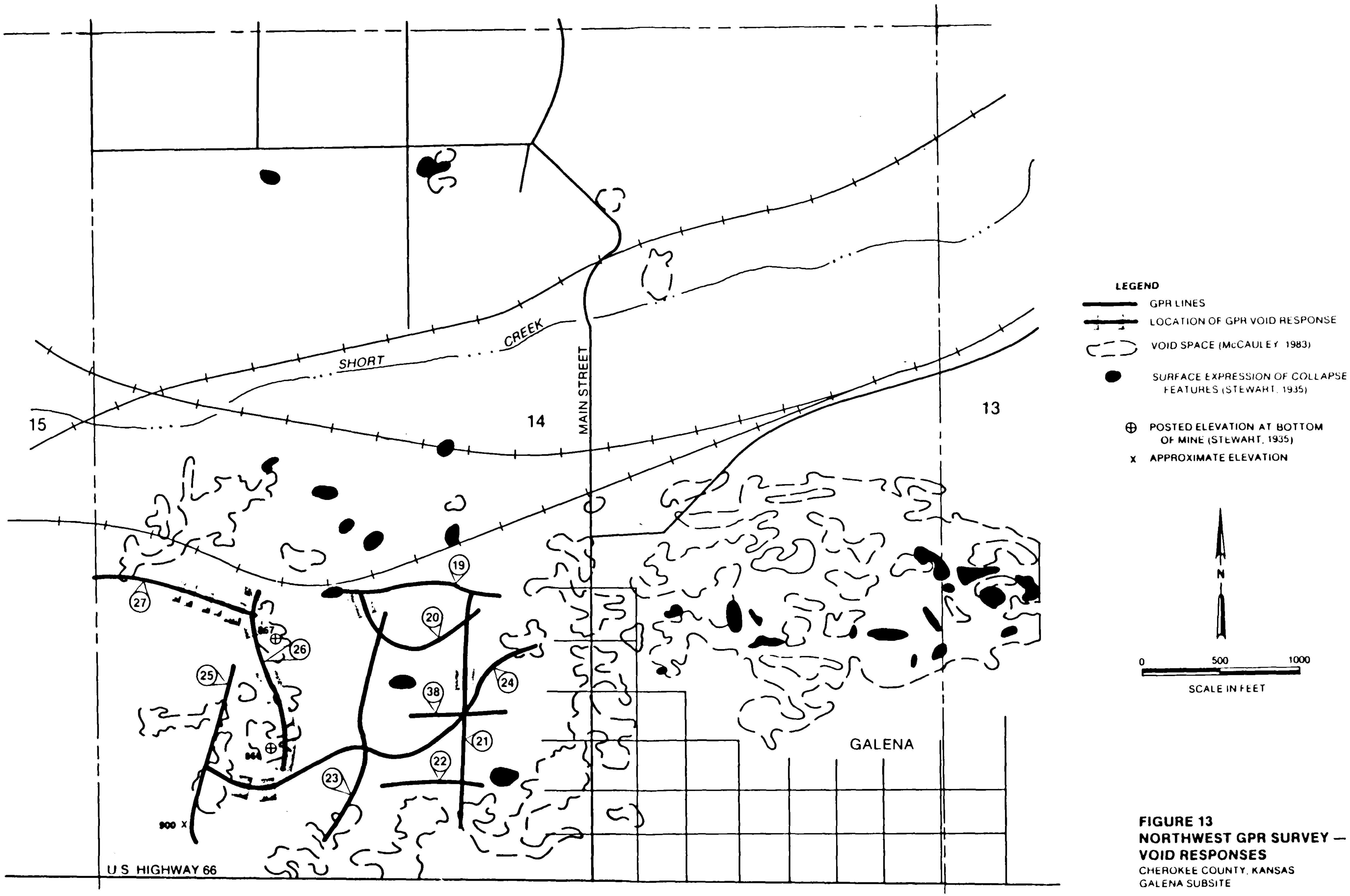


FIGURE 13
NORTHWEST GPR SURVEY — VOID RESPONSES
CHEROKEE COUNTY, KANSAS
GALENA SUBSITE

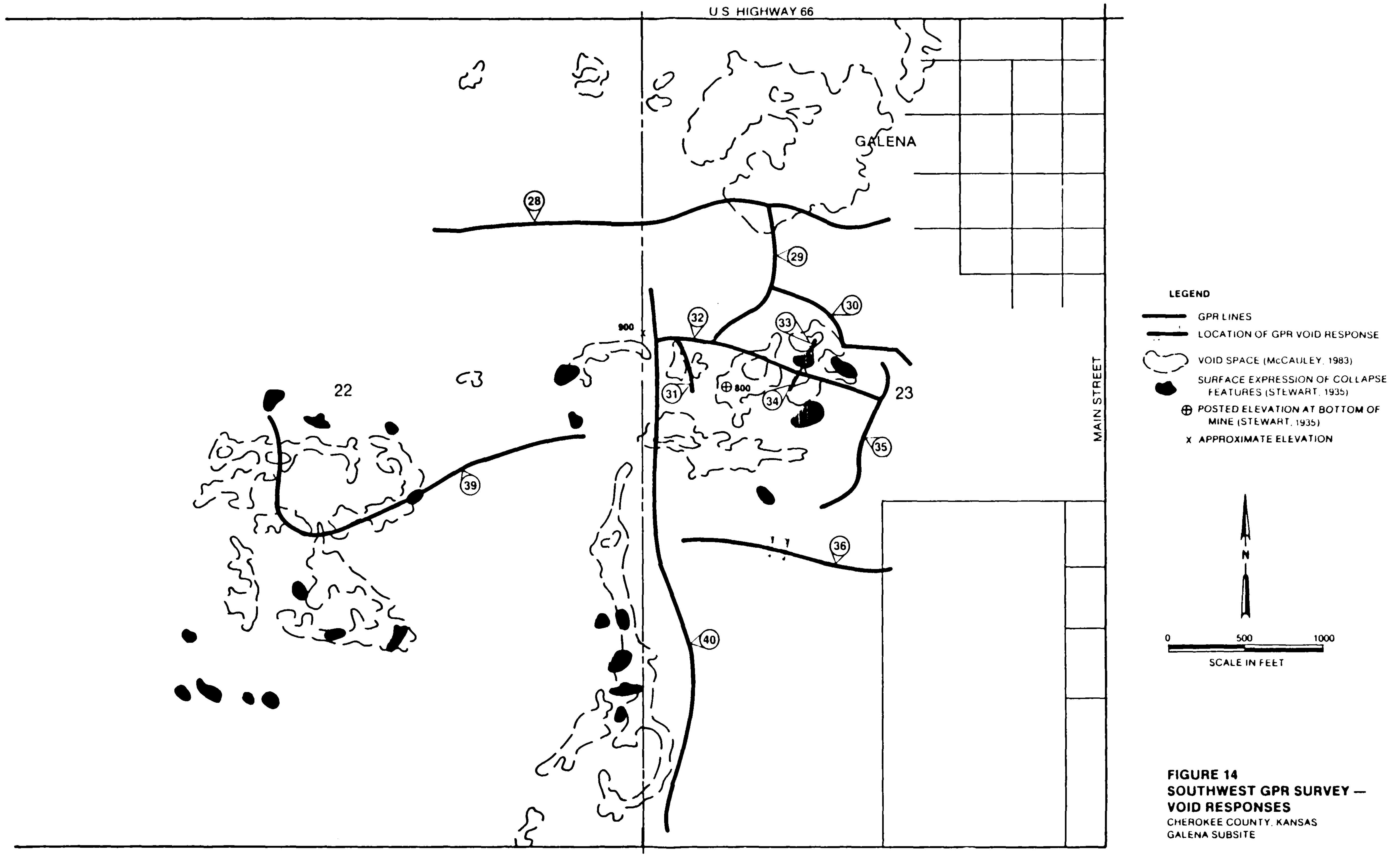


FIGURE 14
SOUTHWEST GPR SURVEY — VOID RESPONSES
CHEROKEE COUNTY, KANSAS
GALENA SUBSITE

The estimated maximum depth of penetration for ground penetrating radar is 40 feet for this site. Because many surface and subsurface phenomena attenuate GPR energy when they are encountered, the coverage depth of penetration is somewhat less than 40 feet. Mine voids deeper than 40 feet will not be detected using GPR. Three out of four of the general localities shown on Figures 11 through 14 are composed predominantly of mine workings deeper than 40 feet. Only the northwest area (Figure 13) was composed of workings predominantly less than 40 feet beneath the ground surface. Additionally, although the majority of Hell's Half Acre is greater than 40 feet deep, the northernmost parts are mostly less than 40 feet deep (Figure 11).

Results of the GPR survey corroborate mine map information. Areas identified as voids on the GPR profiles correlated fairly well with areas identified as mine workings within 40 feet of the surface on the mine maps.

Line 26 in the northwest area and lines 1, 2, and 6 in the Hell's Half Acre area are examples of good agreement between mine map voids and GPR voids. Very few voids were identified in the Blue Hole and Southwest areas. This compares favorably with the maps because of the inability of GPR to detect the estimated 100-foot deep mine workings noted in these areas. The generally good agreement between shallow workings identified on the mine maps and those identified with GPR increases the credibility of GPP results.

Using GPR response pattern recognition, it was possible to define the amount of void space along a line in the surveyed area. By employing the information previously given in Tables 1 and 2, a breakdown of void space along the lines per survey area was made. Table 3 lists this information.

Table 3
PERCENT VOID SPACE ALONG LINES FOR EACH GENERAL AREA

General Area	% Void Space Along Lines	Void Space Along Lines (in feet)	Total Line Distances (in feet)
Hell's Half Acre	20	1,735	8,525
Blue Hole	2	140	9,175
Northwest Area	12	1,530	13,150
Southwest Area	1	125	15,675
Total for Galena Subsite	8	3,530	46,525

A GPR profile is a measure of subsurface response versus corresponding surface location. Because GPR cannot define anything below the roof of a void, it is not possible to use this technique to determine the height of a void space. Graphic profiles obtained using GPR can be used to define width and length of void spaces, but only if a tight grid of GPR lines is run over the area of suspected voids. Terrain conditions in the Galena Subsite did not allow for a tight enough grid to define width of void spaces. Only length of voids was obtained from GPR lines. The percentages in Table 3 were derived from void space length. The use of this percentage to calculate volume of near-surface void spaces involves extrapolation to three dimensions (length, width, and height).

Width can be estimated by assuming the GPR survey provided consistent coverage over each of the four survey areas. By assuming the same percentage of voids will be found within an area as along GPR lines (length dimension), the following calculation extrapolates linear void space into area void space:

$$(2{,}000{,}000\ yd^2) \times (0.08) = 160{,}000\ yd^2$$

(Area of four general localities) x (% linear void space)
= (Area void space within 40 feet of the surface)

For purposes of estimating volume of voids, the average height of the mine workings is assumed to be 10 yards. This number is an approximation, but is probably close to the average, judging by voids that can be observed in the field. Using these assumptions, a volume of 1.6 million cubic yards for voids within 40 feet of the surface is obtained. This represents an estimated volume of voids within 40 feet of the surface. Substantial error in the calculation can result from the extrapolation of linear void space to area void space.

Since GPR has substantiated that the historic mine maps are fairly accurate in their presentation of subsurface void space, a more accurate calculation of total volume of voids would be obtained by using these sources. Such calculations would have the additional benefit of including information deeper than 40 feet beneath the surface.

The interpretation of data collected during this field effort has limitations. These limitations are specific to the GPR method, site-specific parameters (lithology, cultural effects, climate, etc.), and survey design. The following limitations must be considered when interpreting or using GPR data:

- Reflections on a line are derived from composite returns that have been averaged across an interface within an area of radiation. GPR's area of radiation, or what the method effectively "sees," includes areas ahead, behind, and to the side of

an actual ground location. Void space has been interpreted to include distances from the beginning to the end of the typical response on the record. Therefore, the annotated (estimated) size of a void is an estimate. In general, annotated void space is larger than actual void space by approximately 20 feet.

- The scope of this survey included ground checks along each line to try to identify any visible surface causes of anomalies. However, the scope did not include subsurface investigations to ground check for subsurface causes. Such a check would involve substantial effort (for example, drilling) that was not included in the work plan. Patterns may or may not be unique to a subsurface phenomenon. Therefore, interpretations are not absolute ground truth, but are a function of patterns developed in the testing stages of the program.

- The logistics involved in towing a +400-pound sled over rough terrain limited GPR survey lines to driveable terrain. Commonly, this meant following existing roads or paths, many of which were built in areas where there were no subsurface voids. Line locations were, as much as possible, placed to give representative data for a large area.

- Depth conversions were based on material velocity calculations made with site-specific data. It was not possible to derive velocities for each GPR survey line. As such, depth conversions given in this report assume homogeneity and do not reflect localized variations in lithology. This may result in overestimating or underestimating the depth to a particular void or subsurface feature.

SPONTANEOUS POTENTIAL RESULTS

The SP field test was conducted on mined and adjacent unmined areas at the Galena subsite. The objective of the field test was to evaluate the effectiveness of the SP method in identifying oxidation-reduction zones, which might indicate discrete "hot spots," or areas of intense sulfide mineral oxidation. Sulfide mineral oxidation and subsequent solution contribute to metal concentrations in groundwater.

The mechanism that causes an SP response is believed to be related to a zone of oxidation and a zone of reduction, resulting in a voltage difference between these two zones. Figure 15 shows what a typical SP profile over a discrete sulfide body looks like. The pronounced depression in the profile over the sulfide body is a characteristic response that was sought in the SP test data.

Four lines of representative data were acquired in locations shown in Figure 16.

An interpretation of the SP profile along each line follows.

Line 1

Line 1 was chosen because we expected it to include an area of oxidation near an open pit (marked "pond area" on Figures 16 and 17). The data throughout line 1, except in this pond area, is erratic and noisy. The characteristic negative voltage maximum over a sulfide body (Figure 15) was not observed on this line. The stability in the pond area may be the result of homogeneous ground or a constant water table.

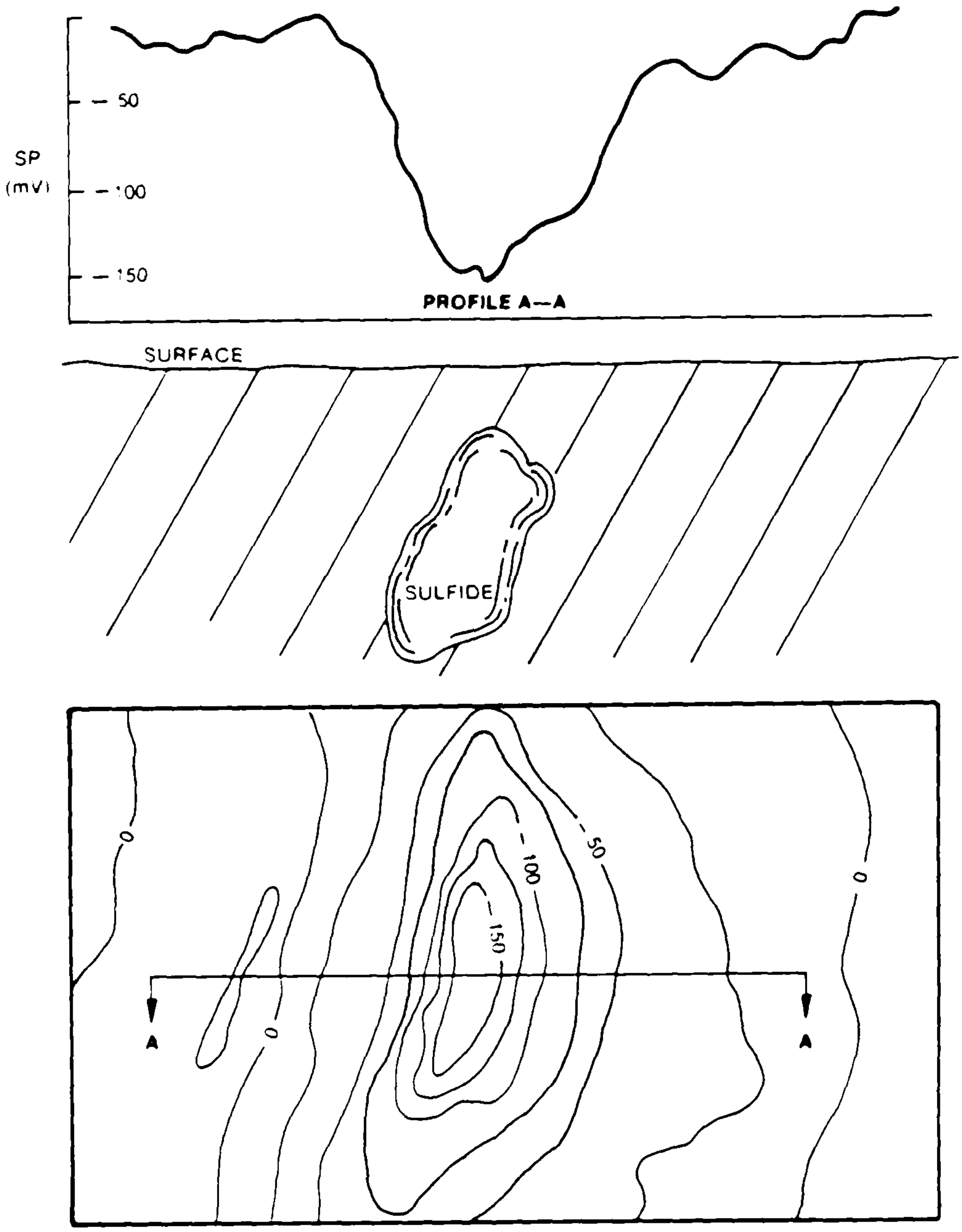
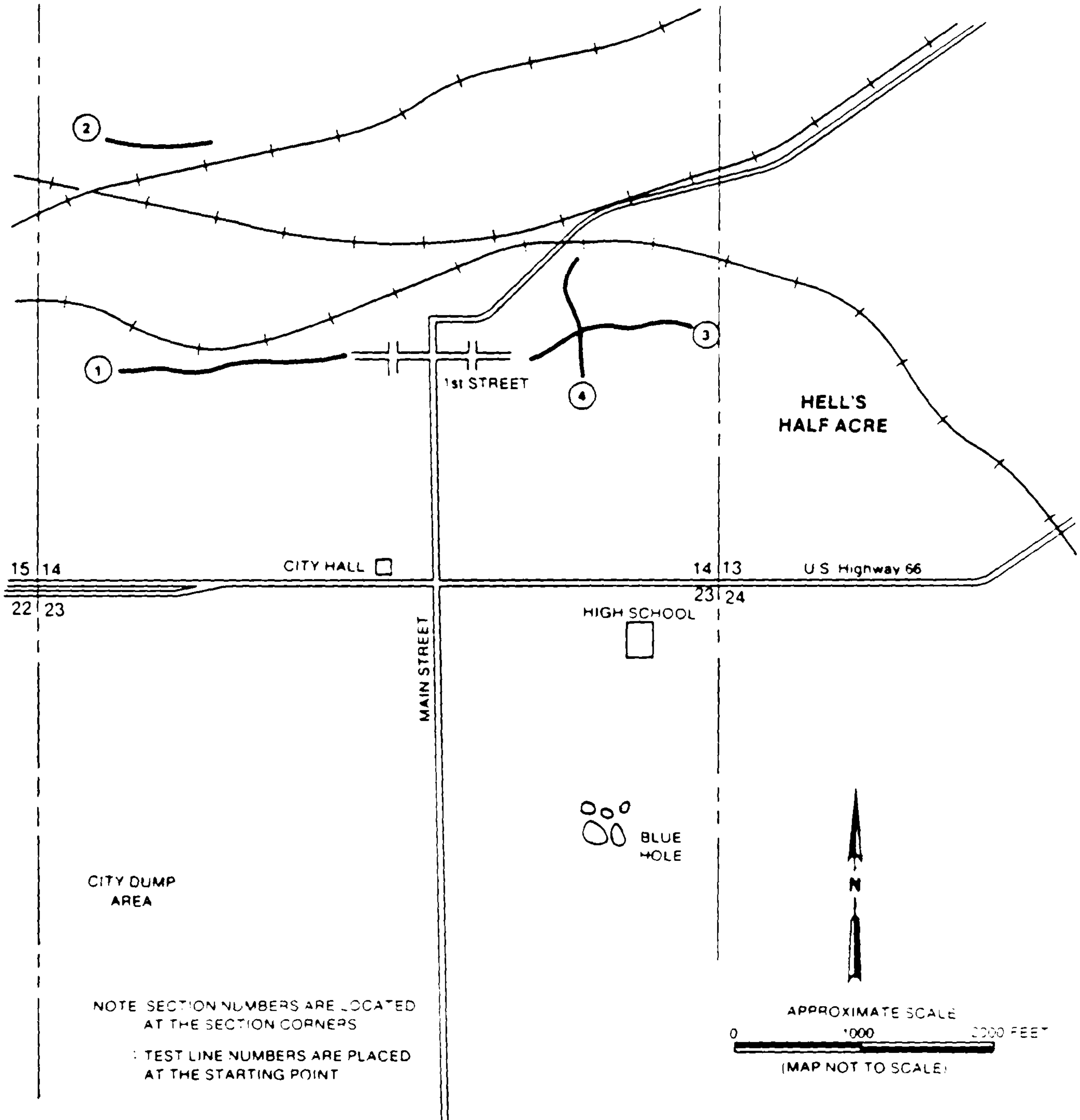
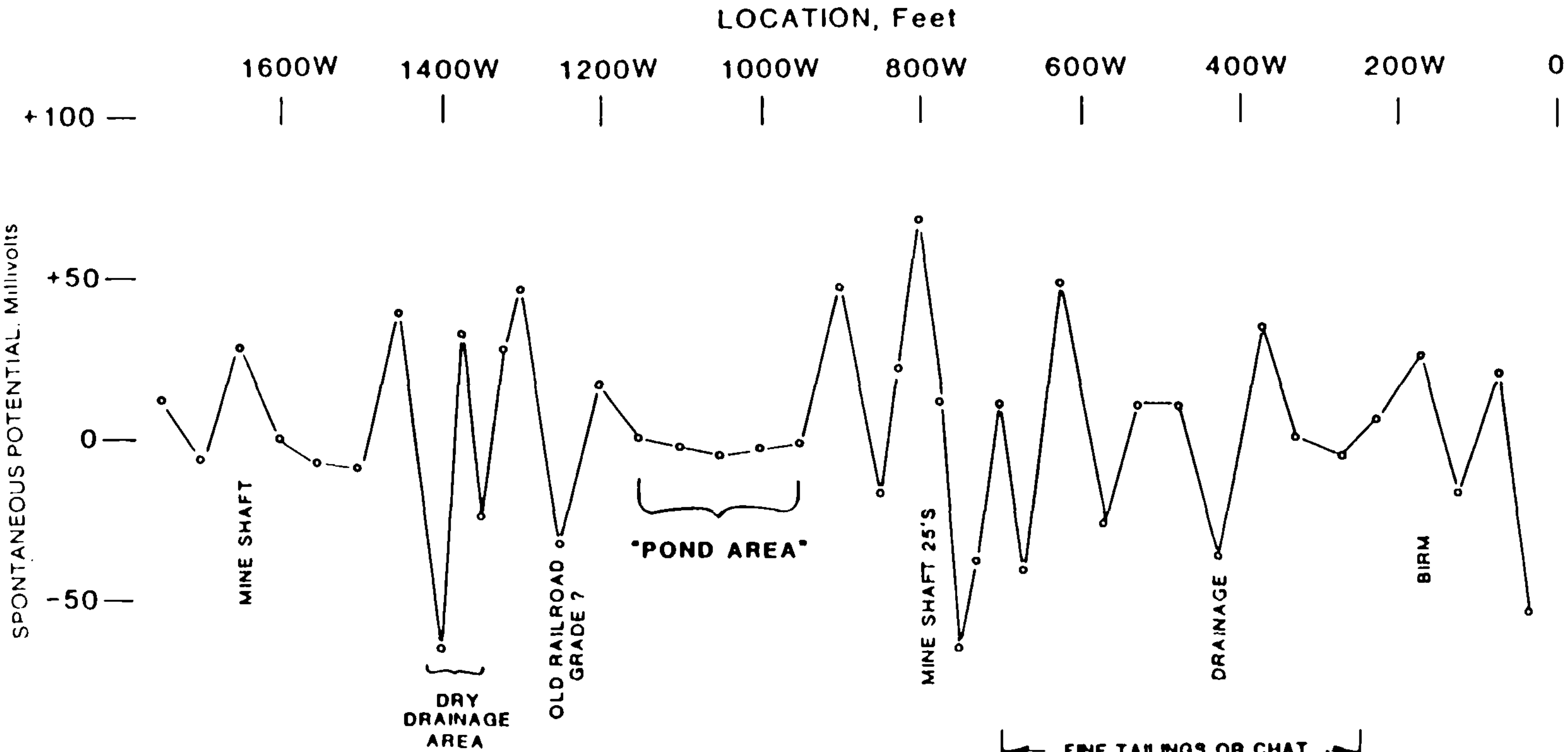


FIGURE 15
TYPICAL SPONTANEOUS POTENTIAL PROFILE AND CONTOURS — SULFIDE BODY
CHEROKEE COUNTY KANSAS
GALENA SUBSITE



TEST 1 - WEST FIRST STREET LINE
TEST 2 - NORTH LINE
TEST 3 - EAST FIRST STREET LINE
TEST 4 - NORTH HELL'S HALF ACRE LINE

FIGURE 16
SPONTANEOUS POTENTIAL — LOCATION OF TEST SURVEYS
CHEROKEE COUNTY, KANSAS
GALENA SUBSITE



DRIFT MEASUREMENT @ 0 - 25 WEST
10:43 A.M. - 51.2mv
3:30 P.M. - 64.7mv

7/30/87

VERTICAL SCALE: 1" = 50 millivolts

HORIZONTAL SCALE: 1" = 200 feet

DIPOLE SPACING = 50 feet

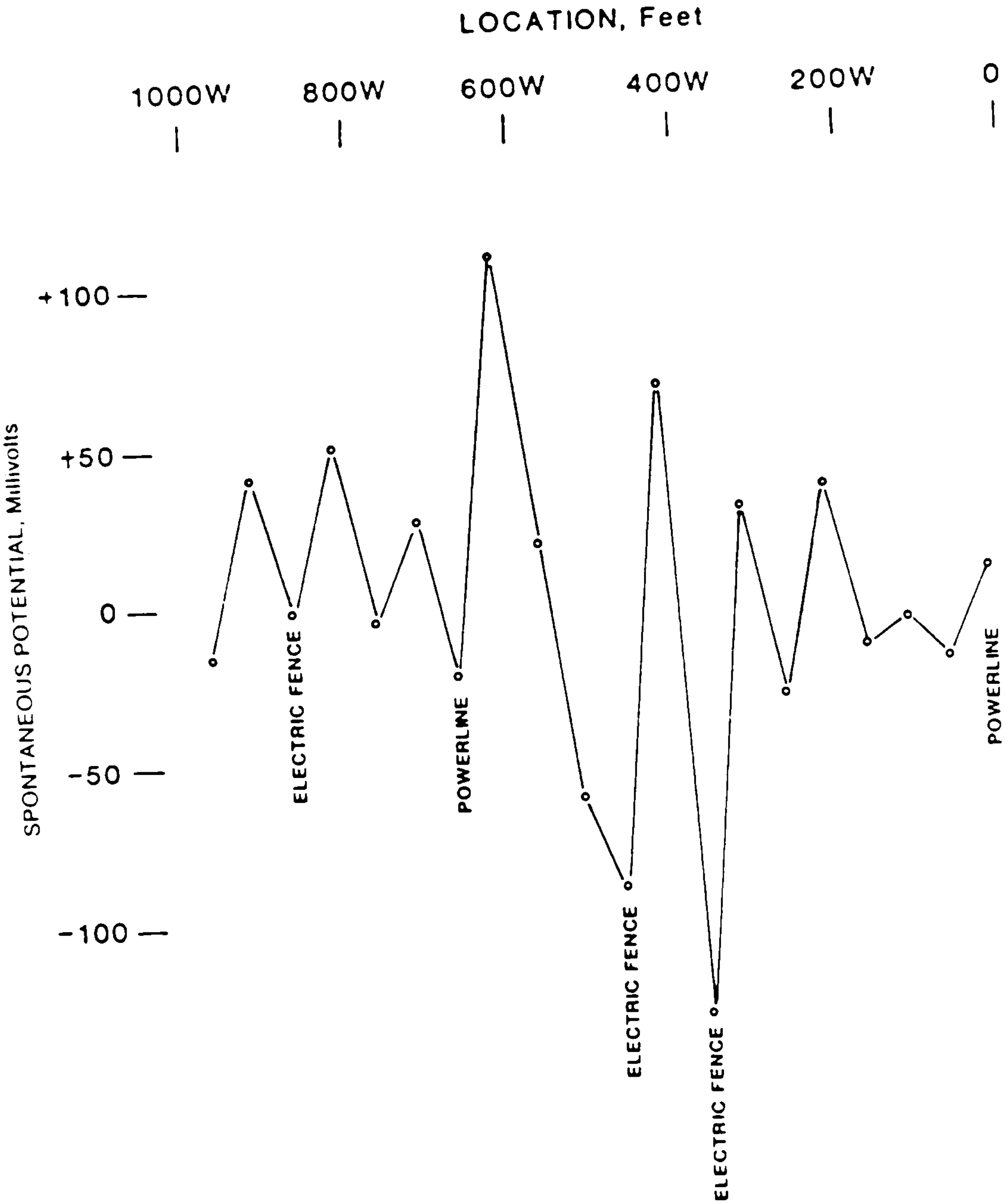
FIGURE 17
SPONTANEOUS POTENTIAL TEST SURVEY — LINE 1
CHEROKEE COUNTY KANSAS
GALENA SUBSITE

Line 2

Line 2 was selected because it was anticipated to have a relatively undisturbed surface (no visible sign of mining) (Figures 16 and 18). The objective of this line was to determine if the erratic characteristics seen in line 1 were specifically related to the nonhomogeneous disturbed surface areas in the northwest survey area. Line 2 data proved to be erratic due to cultural features (such as electric fences and power lines), as well as to a nonhomogeneous surface. The characteristic negative voltage maximum over a sulfide body (Figure 15) was not observed on this line. Voltage measurements noted on line 1 indicated a change of 13.5 millivolts between the period of the beginning of line 1 and the end of line 2. A drift of this magnitude is expected given a highly erratic voltage potential.

Lines 3 and 4

In completing the SP field test, lines 3 and 4 (Figure 19 and Figure 20) were chosen to evaluate effectiveness of the method within areas for which no information on oxidation zones was available. Line 3 data exhibited noisy and erratic patterns, as well as the nonrepeatability of a data point with only a slight movement of the porous-pot electrodes. Line 4 data also exhibited erratic behavior. The characteristic negative voltage maximum over a sulfide body (Figure 15) was not observed on this line. Voltage drift measurements indicated a change of 40 millivolts between the period of the beginning of line 3 and the end of line 4. As mentioned previously, a drift of this magnitude is indicative of a highly erratic voltage potential.



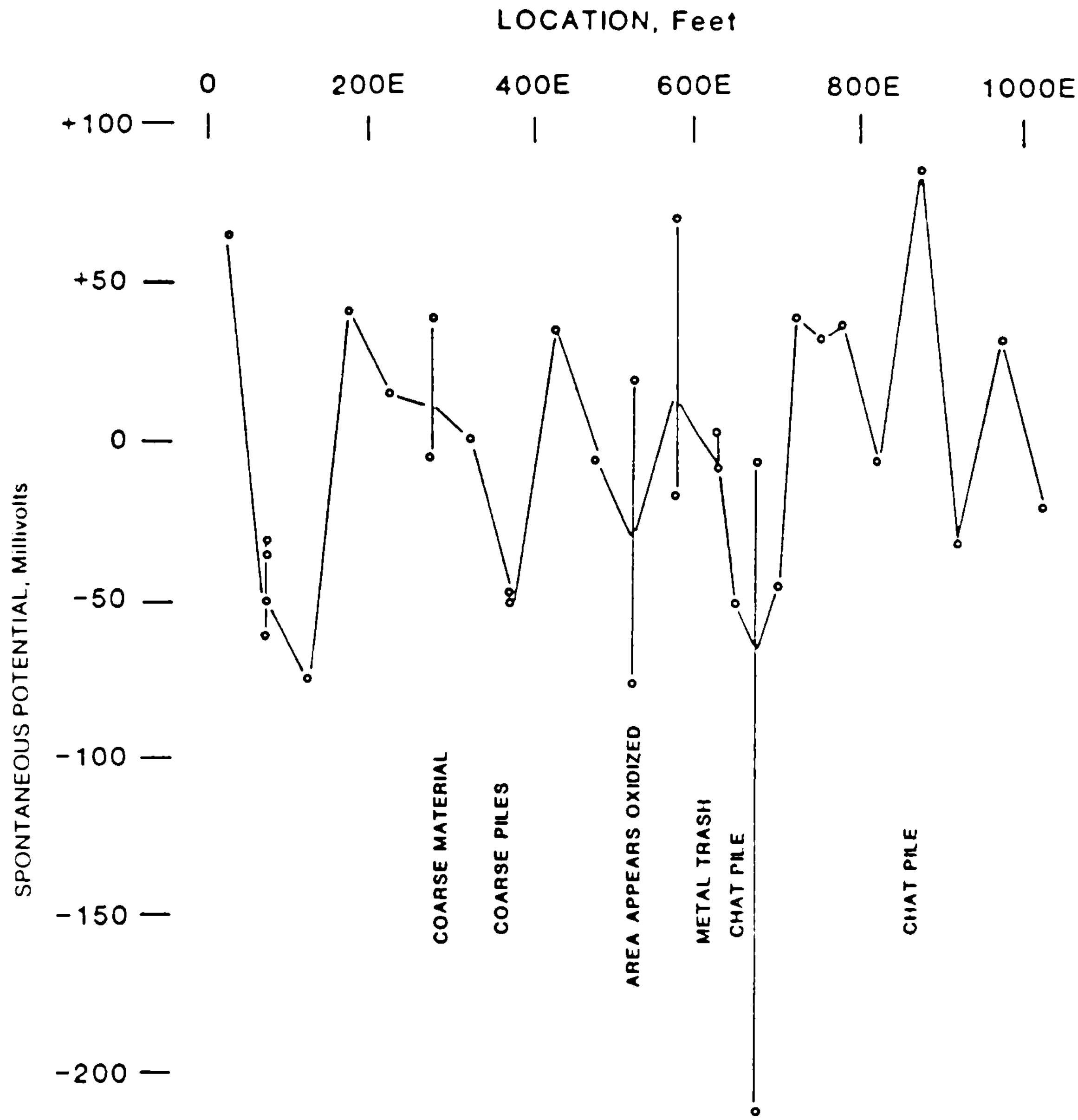
7/30/87

VERTICAL SCALE: 1" = 50 millivolts

HORIZONTAL SCALE: 1" = 200 feet

DIPOLE SPACING = 50 feet

FIGURE 18
SPONTANEOUS POTENTIAL TEST SURVEY — LINE 2
CHEROKEE COUNTY KANSAS
GALENA SUBSITE



DRIFT MEASUREMENT

@ 0 - 25 EAST

1:30 P.M. + 66mv

4:55 P.M. + 26mv

SUCCESSIVE READING MOVING POROUS POTS SLIGHTLY

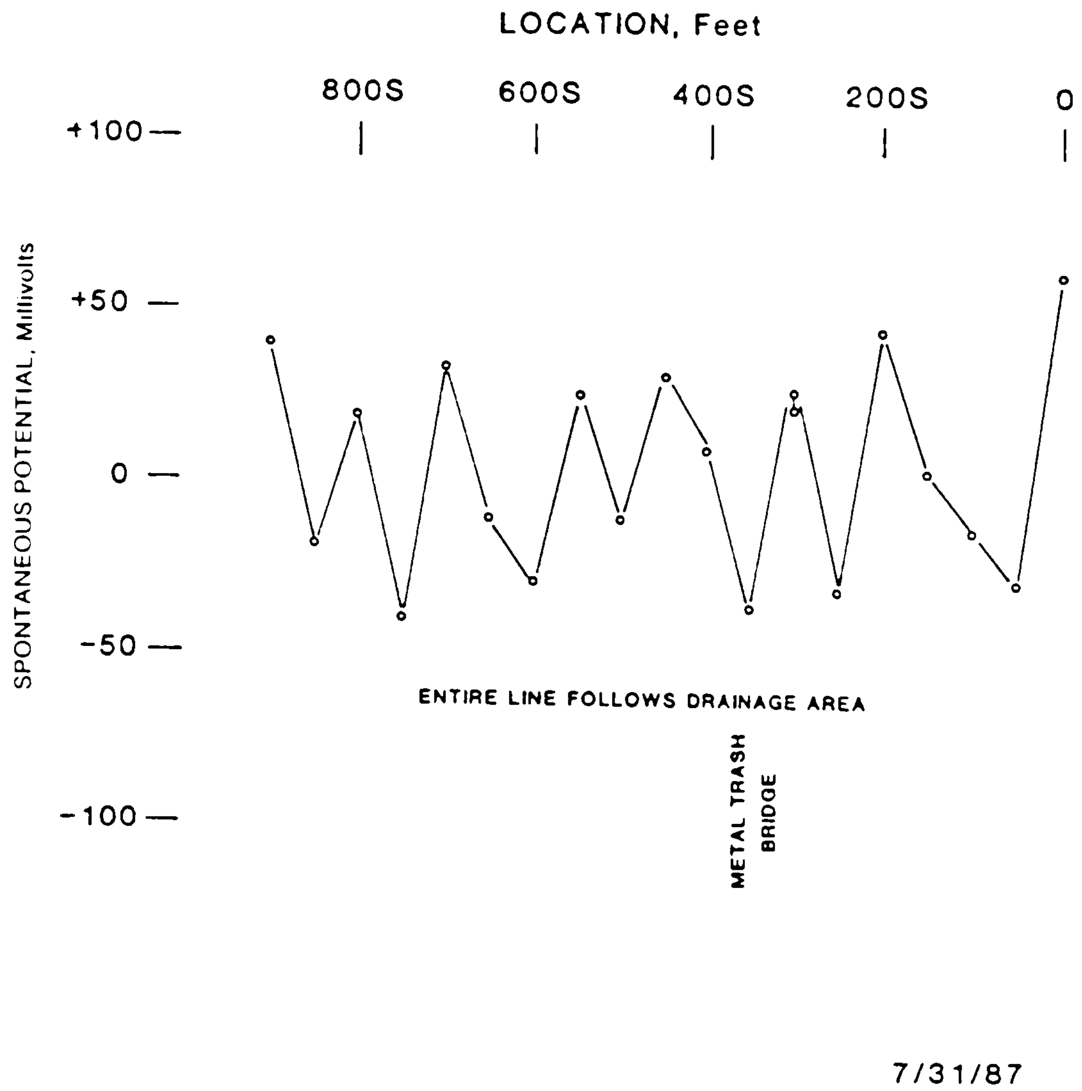
VERTICAL SCALE: 1" = 50 millivolts

HORIZONTAL SCALE: 1" = 1200 feet

DIPOLE SPACING = 50 feet

7/31/87

FIGURE 19
SPONTANEOUS POTENTIAL TEST SURVEY — LINE 3
CHEROKEE COUNTY KANSAS
GALENA SUBSITE



VERTICAL SCALE: 1" = 50 millivolts

HORIZONTAL SCALE: 1" = 200 feet

DIPOLE SPACING = 50 feet

FIGURE 20
SPONTANEOUS POTENTIAL TEST SURVEY — LINE 4
CHEROKEE COUNTY, KANSAS
GALENA SUBSITE

SUMMARY

GROUND PENETRATING RADAR

The GPR survey method proved to be effective in defining the approximate location and extent of shallow mine workings in the survey areas. The following results were obtained from the GPR survey:

- o Depths to voids across the site that could be detected with GPR varied from 6 to 40 feet.

- o Results of the GPR survey corroborate mine map information. The overall good correlation of voids on the GPR profiles with areas identified as mine workings within 40 feet of the surface on mine maps increases the credibility of GPR results.

- o Void space along lines within the upper 40 feet of each general area varied from a low of 1 percent in the Southwest Area to a high of 20 percent for the Hell's Half Acre. The combined total for the four general areas within the Galena Subsite was 8 percent.

- o Based on length of void space along lines and using an approximation to calculate void width and height, a total void space volume within the top 40 feet of site of 1.6 million cubic yards was calculated.

The GPR survey method proved to be ineffective in defining the water table elevations.

The presence of water in this terrain may act as an attenuator of GPR energy. The same factors that have contributed to great depths of penetration of up to 40 feet (lithology,

climate, lack of vegetation, etc.) may, in the presence of water, combine to yield a lack of penetration (Olhoeft, 1984).

SPONTANEOUS POTENTIAL

The SP method did not indicate areas of discrete oxidizing sulfides at the Galena Subsite. The entire area tested showed nonhomogeneities at or near the ground surface. The dry, highly resistive surface materials probably were not well coupled with SP cells set up at the water table. No other geophysical method is so adversely affected by near-surface conditions as the SP method is. Variability in the SP responses is a byproduct of the effects of weathering within surface materials and is not the result of small-scale "cells" of oxidizing materials.

REFERENCES

EPA 1986. Final Draft, Phase I Remedial Investigation Report, Cherokee County, Galena Subsite. April.

EPA 1987. Work Plan, Supplementary Remedial Investigations for the Galena Subsite Mine Wastes Characterization and Geophysics. Cherokee County Site. May 1987.

EPA 1988. Groundwater and Surface Water Operable Unit Feasibility Study. Galena Subsite, Cherokee County Site, Kansas. February 26, 1988.

Hara, T., and T. Sakayama. 1983. Subsurface exploration using ground-probing radar. Technical Publication No. 4, Application to Underground Cavities. English version of presentation to the Society of Exploration Geophysicists of Japan, fall meeting, Okayama, October 6 through 7, 1983.

McCauley, J. R., L. L. Brady, and F. W. Wilson. 1983. A Study of Stability Problems and Hazard Evaluation of the Kansas Portion of the Tri-State Mining Area. U.S. Department of the Interior. Bureau of Mines Contract J0100131.

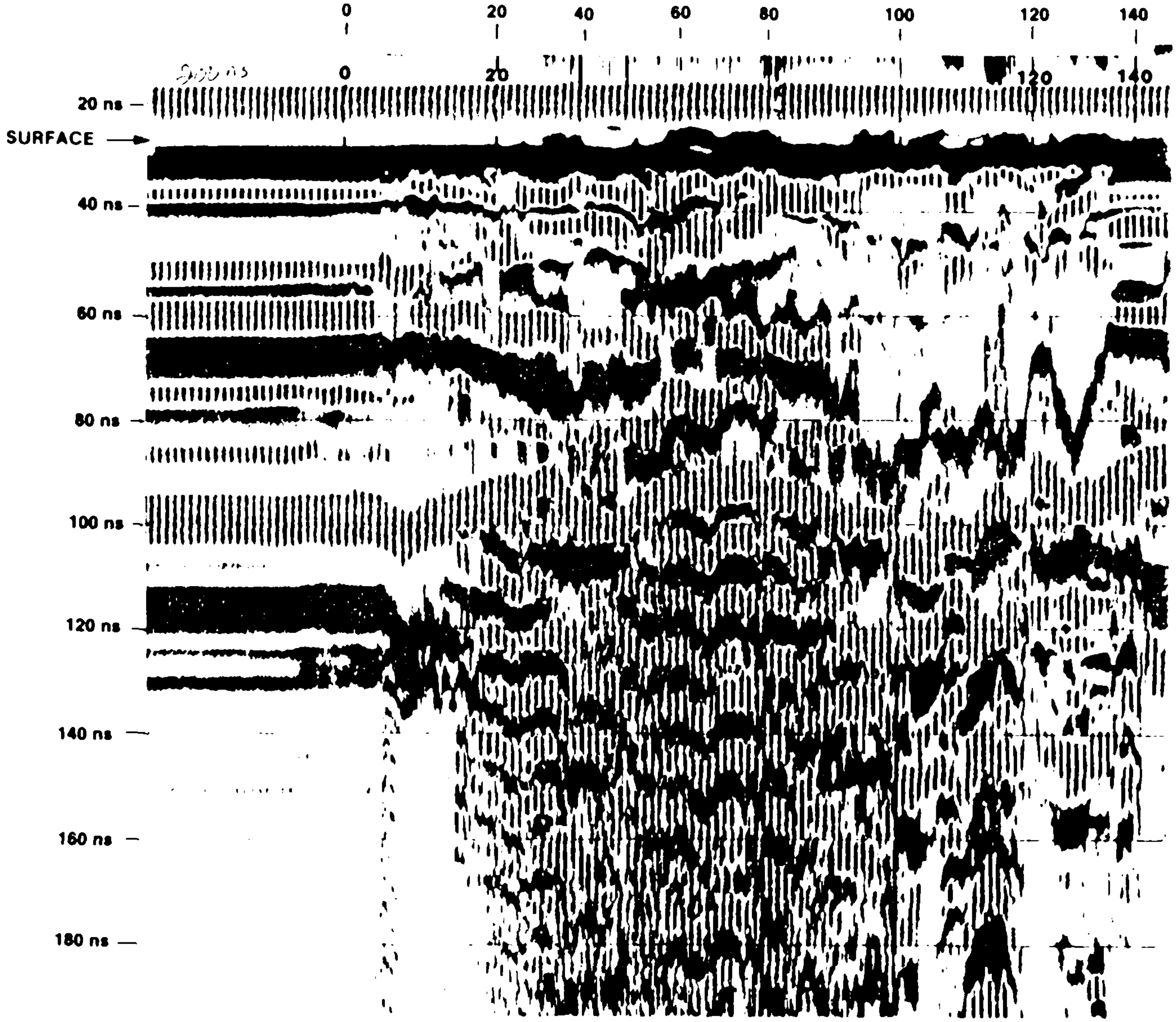
Olhoeft, G. R. 1984. Applications and limitations of ground-penetrating radar. In Expanded Abstracts, 54th Annual International Meeting and Exposition, December 2 through 6, 1984, Atlanta, GA, pp. 147-148.

Shih, S. F., J. A. Doolittle, D. L. Myhre, and G. W. Schellentrager. 1986. Using radar for groundwater investigation. Journal of Irrigation and Drainage Engineering, Volume 112, No. 2, May 1986, pp. 110-118.

Stewart, William M. 1935. Map: "Galena Mining District, March 1935." Acquired from Daniel Stewart and available through CH2M HILL.

Telford, W. M., L. P. Geldant, R. E. Sheriff, and D. A. Keys. 1976. Applied Geophysics, Cambridge University Press, New York, New York, 860 pp.

Appendix A
ANNOTATED GPR SURVEY LINES



GPR Test Line run on
top of field checked void

FIGURE A-1
GPR TEST LINE A
80 MEGAHERTZ BISTATIC ANTENNA
200 NANOSECONDS FULL SCALE
CHEROKEE COUNTY KANSAS
GALENA SUBSITE

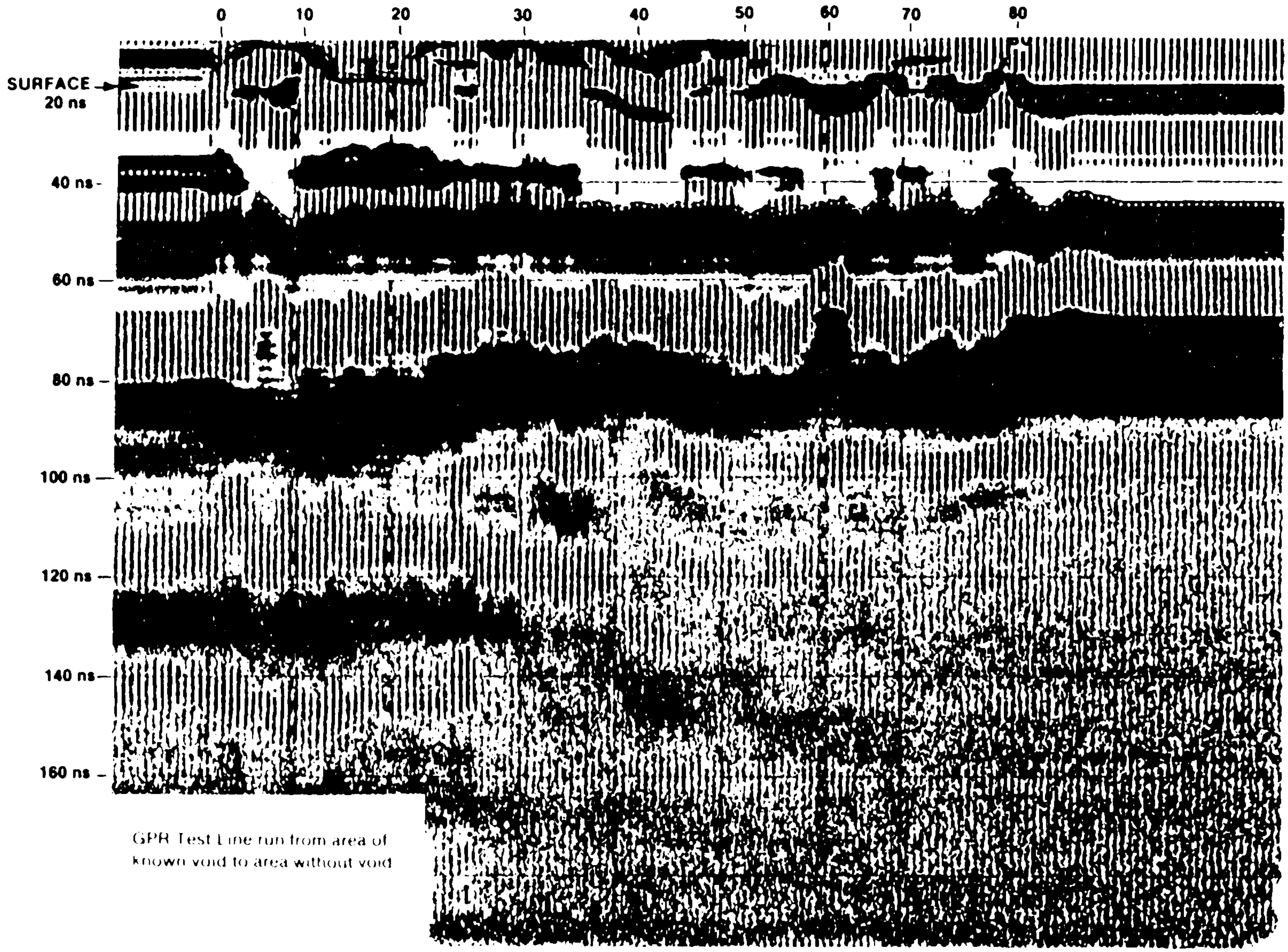
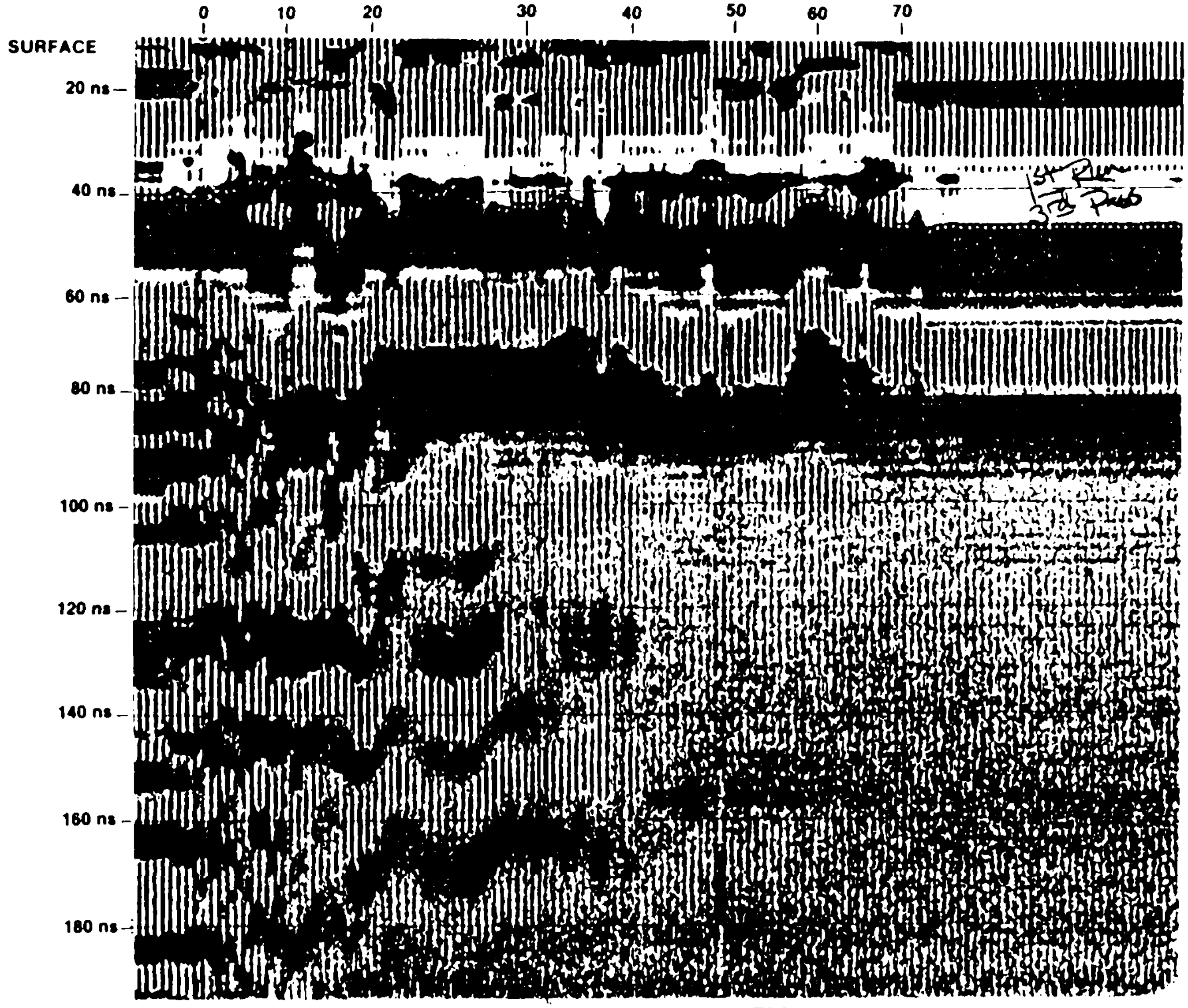


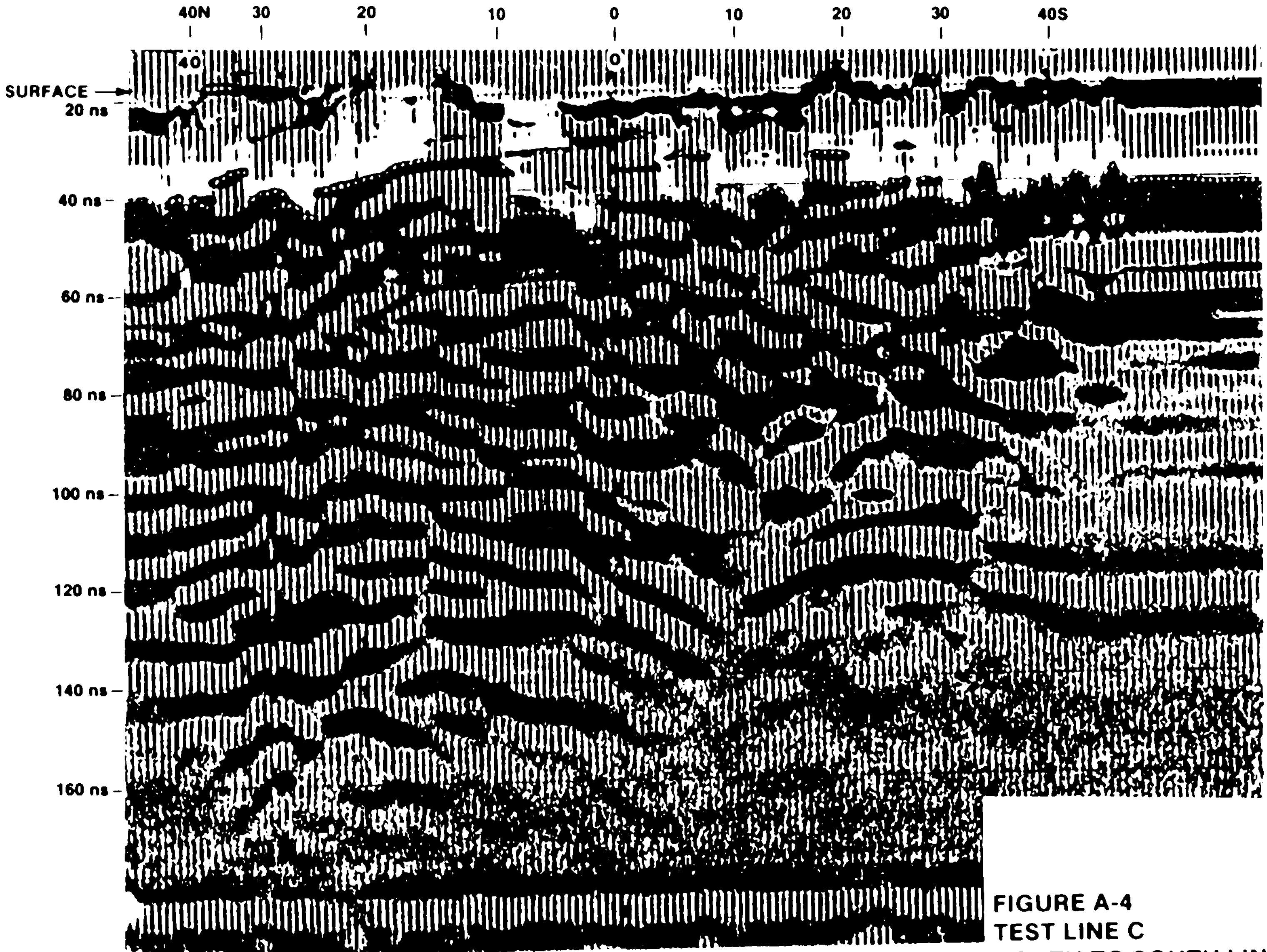
FIGURE A-2
TEST LINE B
WEST TO EAST LINE
300 NANOSECONDS FULL SCALE
CHEROKEE COUNTY, KANSAS
GALENA SUBSITE



GPR Test Line run from area of known void to area without void

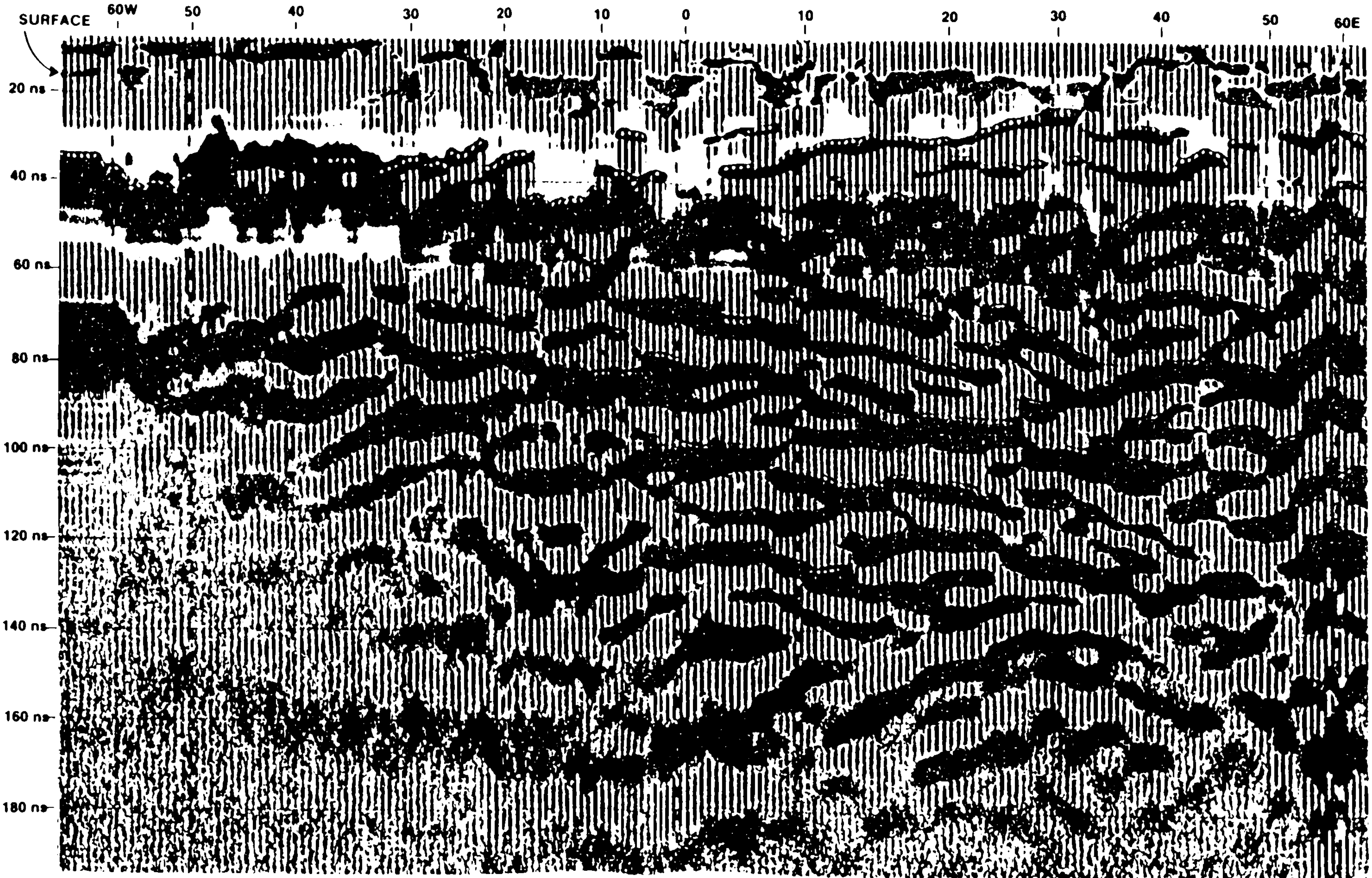
FIGURE A-3
TEST LINE B
SOUTH TO NORTH LINE
300 NANOSECONDS FULL SCALE

CHEROKEE COUNTY, KANSAS
GALENA SUBSITE



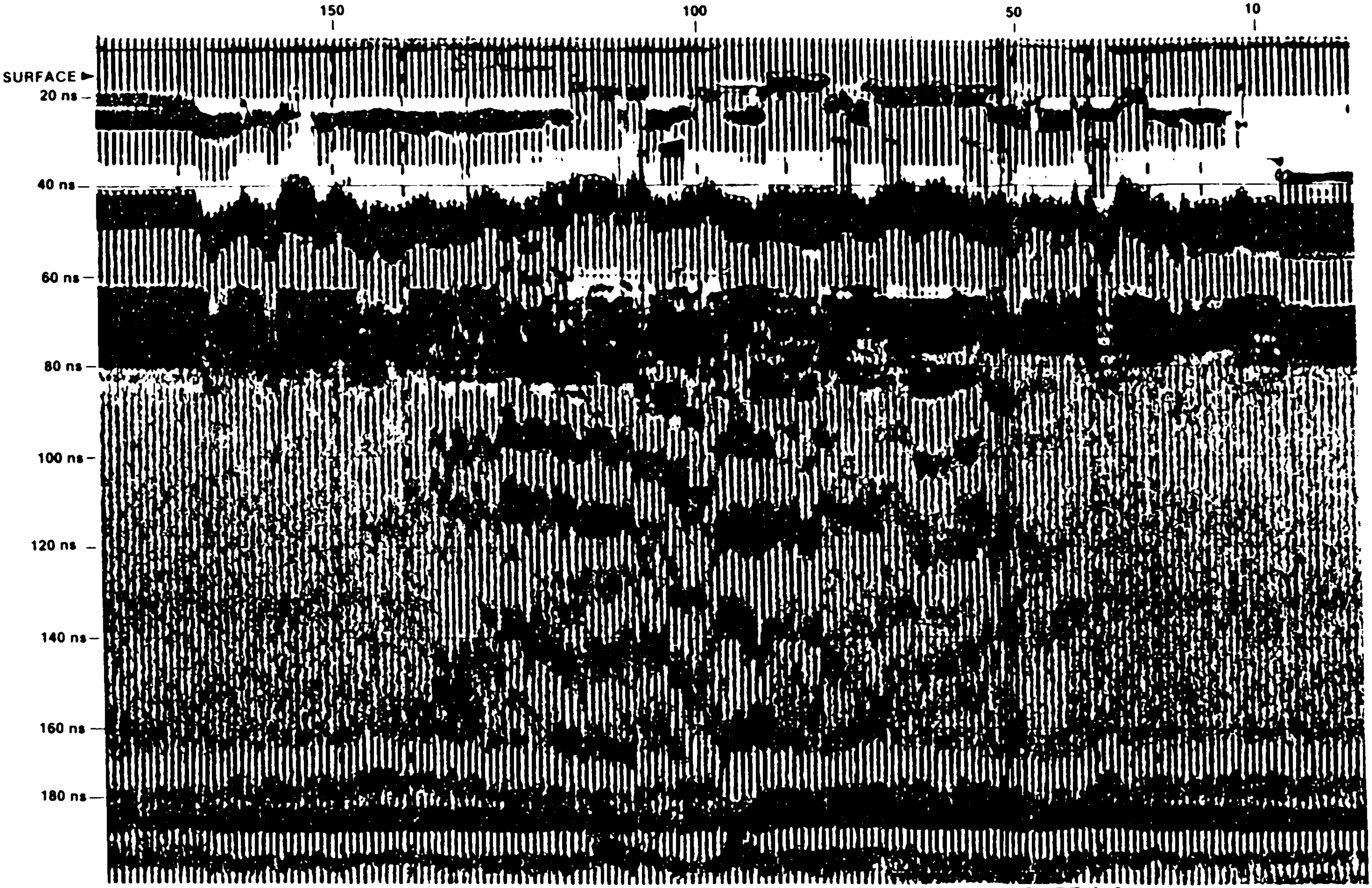
GPR Test Line run on
top of field checked void

FIGURE A-4
TEST LINE C
NORTH TO SOUTH LINE
350 NANOSECONDS FULL SCALE
CHEROKEE COUNTY, KANSAS
GALENA SUBSITE



GPR Test Line run on
top of field checked void

FIGURE A-5
TEST LINE C
WEST TO EAST LINE
300 NANOSECONDS FULL SCALE
CHEROKEE COUNTY, KANSAS
GALENA SUBSITE



GPR Test Line run on
top of field checked void

FIGURE A-6
TEST LINE D
WEST TO EAST LINE
350 NANOSECONDS FULL SCALE

CHEROKEE COUNTY, KANSAS
GALENA SUBSITE

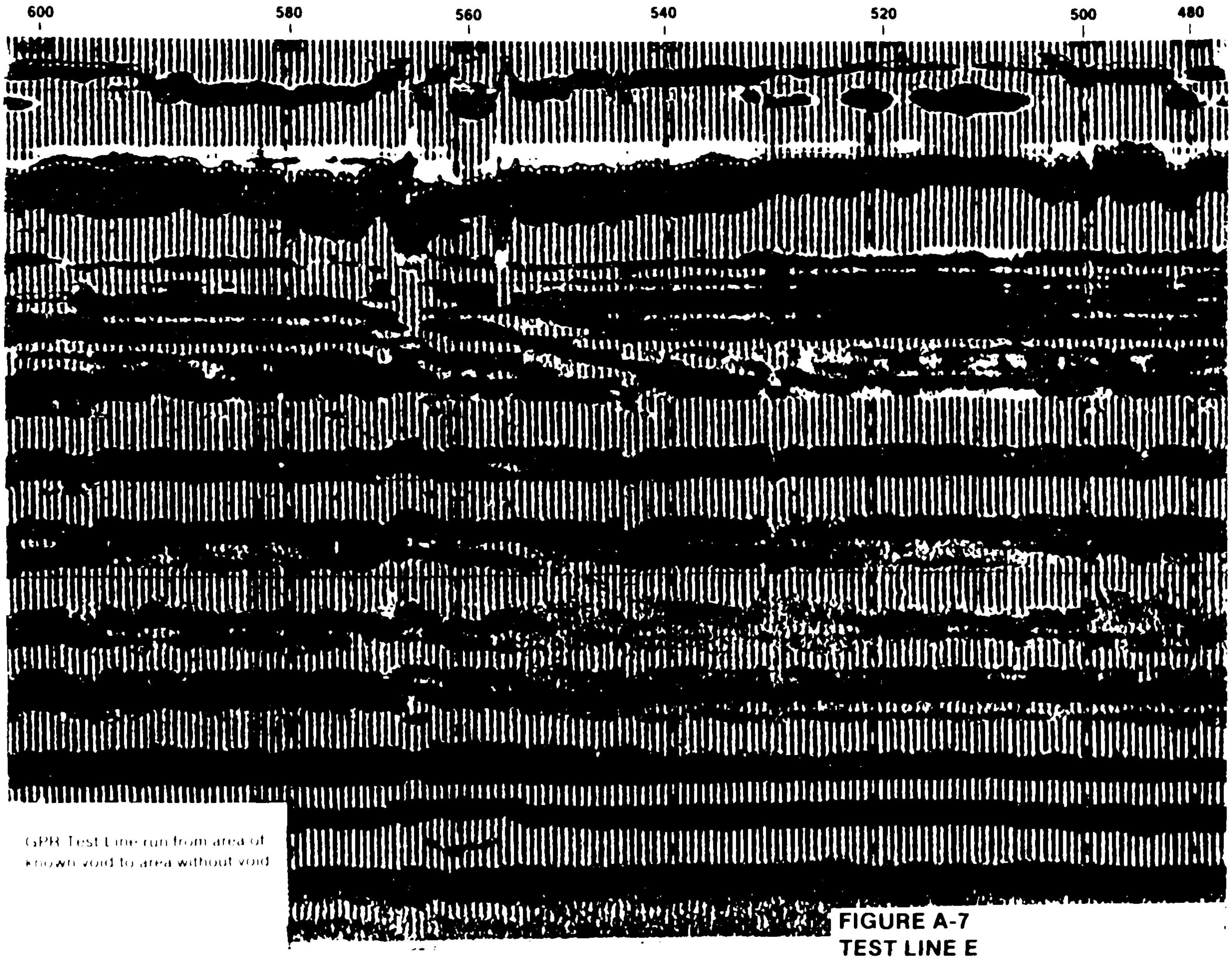


FIGURE A-7
TEST LINE E
NORTH TO SOUTH LINE
400 NANOSECONDS FULL SCALE
CHEROKEE COUNTY, KANSAS
GALENA SUBSITE

Appendix B
SP TEST LINES

(Appendix B has already been submitted with the Draft Ground Penetrating Radar and Spontaneous Potential Technical Memorandum to the U.S. Environmental Protection Agency.)